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Evaluation of Operational Factors Contributing to Reduced Recharge Capacity, North Boundary Treatment System, Rocky Mountain Arsenal, Commerce City, Colorado

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Rocky Mountain Arsenal

WES

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Prepared for U.S. Army Program Manager for Rocky Mountain Arsenal

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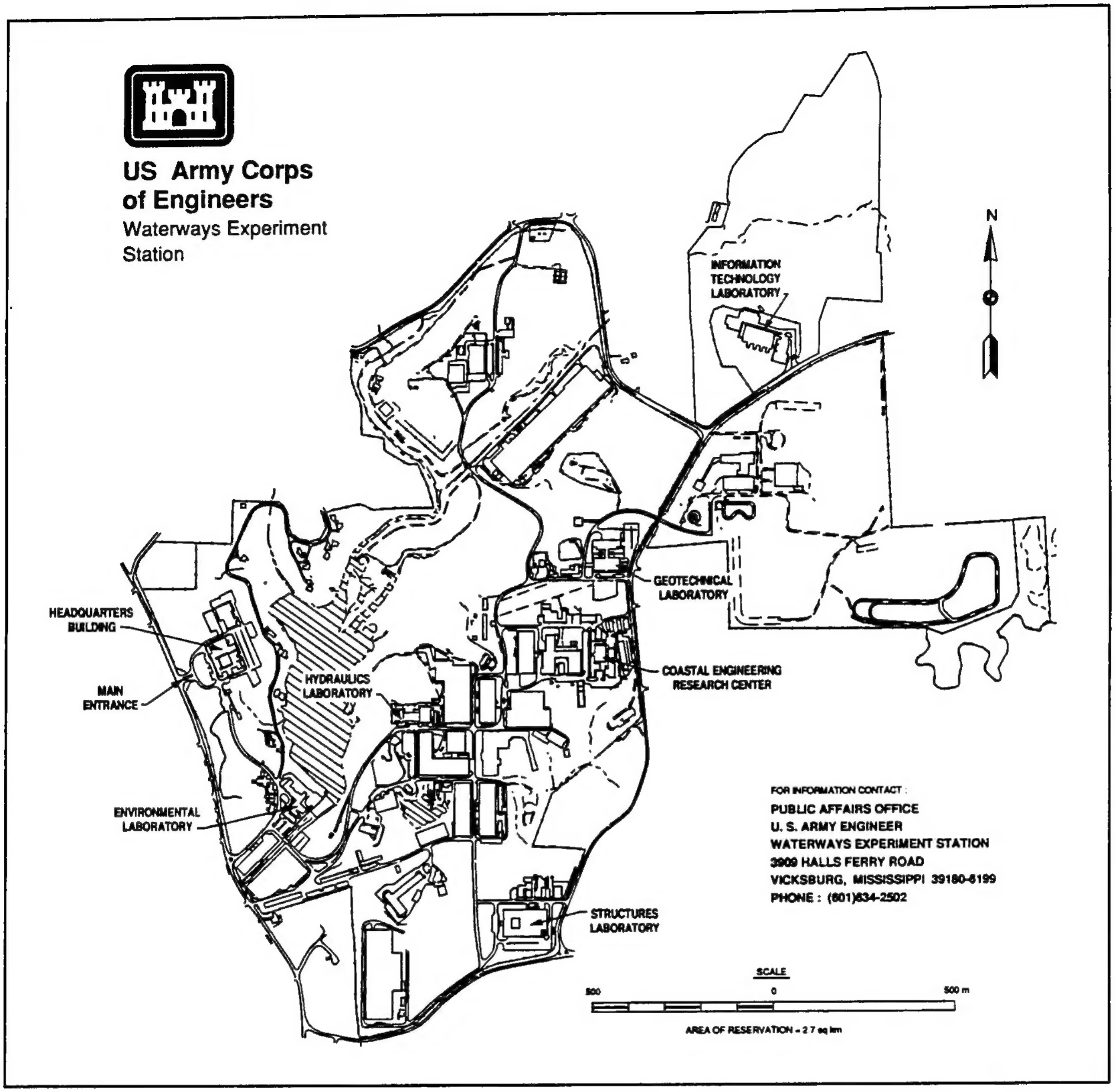

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PREFACE

This study was conducted by the US Army Engineer Waterways Experiment Station (WES) upon request from the Technical Operations Division (TOD) of the Program Manager Staff Office of the Rocky Mountain Arsenal (PMRMA) to assess the potential for reduced recharge capacity of the recharge system at the North Boundary, Rocky Mountain Arsenal (RMA). Funding for participation by WES was provided by the PMRMA via Military Interdepartmental Purchase Request No. 0722. Coordination and management support was provided by Rocky Mountain Arsenal. Project Management was provided by Messrs. David W. Strang, TOD, RMA, and Mark E. Zappi, Environmental Laboratory (EL), WES. This report covers work conducted during the period September 1988 through August 1992.

The study was conducted and the report prepared by Ms. Cynthia L. Teeter and Messrs. Mark E. Zappi and Norman R. Francingues of the Environmental Restoration Branch (ERB), Environmental Engineering Division (EED), and Dr. Douglas Gunnison of the Ecosystem Processes and Effects Branch (EPEB), Environmental Processes and Effects Division (EPED), EL. The Environmental Chemistry Branch, EED, under the supervision of Ms. Ann B. Strong, assisted with the chemical analysis of samples. Ms. Cynthia Price and Mr. Glenn Myrick, EPEB, and Mr. Buddy Ragsdale, ERB, assisted with sample collection and microbial investigations. The University of Mississippi Biology Department sampled the recharge wells for bacteriological enumeration and identification. Particle size analysis was conducted by Particle Data Laboratories Ltd., Elmhurst, Illinois.

The study was conducted under the general supervision of Mr. Norman R. Francingues, Jr., Chief, ERB, Dr. Richard Price, Chief, EPEB, Dr. Raymond L. Montgomery, Chief, EED, Mr. Donald L. Robey, Chief, EPED, and Dr. John Harrison, Director, EL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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CONTENTS

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
gallons (US liquid)	3.785412	liters
pounds (mass)	0.4535924	kilograms

EVALUATION OF OPERATIONAL FACTORS CONTRIBUTING TO REDUCED RECHARGE CAPACITY, NORTH BOUNDARY TREATMENT SYSTEM, ROCKY MOUNTAIN ARSENAL, COMMERCE CITY, COLORADO

PART I: INTRODUCTION

Purpose of Report

1. Since 1988, the US Army Engineer Waterways Experiment Station (WES) has been assessing the performance of the solids removal and recharge capacity of the North Boundary System (NBS) at the Rocky Mountain Arsenal (RMA). Three separate but interrelated tasks have been completed by WES between 1988 and 1992. To date, the results of these tasks have been relayed to RMA personnel in the form of on-site briefings and project summaries. These tasks have contributed to the redesign and improvement of the NBS undertaken by RMA and Shell Chemical as part of an Interim Response Action (IRA) at the North Boundary. The three tasks discussed in this report are:

a. Assessment of the fate of carbon fines throughout the NBS.

b. Evaluation of the potential for reduced recharge capacity of the recharge wells because of excessive microbial growth within the wells.

c. Evaluation of the potential for reduced recharge capacity of the recharge trenches because of excessive microbial growth within the trenches.

2. The findings of these three tasks may be applicable to other pump-and-treat systems operating at RMA. Therefore, at the request of the Office of Program Manager, RMA (PMRMA), this report has been prepared to document the results of various efforts undertaken by PMRMA and WES to date at the NBS concerning carbon fine fate and reductions in recharge system capacity.

Background

3. The NBS was designed to collect and remove contaminated groundwater from the alluvial aquifer and inject treated groundwater back into the aquifer at RMA, Commerce City, Colorado. Before installation of the recharge trenches, the NBS has been unable to properly distribute the treated water

along the North Boundary because of continual clogging of the recharge wells (Thompson et al. 1985).

4. In most cases, reductions in flow capacity of recharge wells can be attributed to one or more of the following: air binding, sodium adsorption, metal precipitation, deposition of cementing agents, straining of suspended solids, and microbial fouling (Todd 1960; Sniegocki 1965). Air binding was ruled out because the plant effluent has sufficient time in the NBS effluent sump to reach air adsorption equilibrium with the atmosphere. The adsorption of sodium by the aquifer surrounding the recharge wells can cause a reduction in permeability (Todd 1960); however, this does not seem likely because the same groundwater is removed from the alluvial aquifer, treated, and then recharged back into the alluvial aquifer without significantly changing sodium concentration. Precipitation of metals and deposition of cementing agents is possible, but based on the effluent pH and hydraulic retention time within the wells, probably not significant. Therefore, the main focus of this study was directed toward assessing the potential for clogging of the recharge wells with carbon fines and/or microbial fouling.

5. A 1988 evaluation of operational problems at the NBS concluded that periodic cleaning of the recharge wells produced limited success in rejuvenating the wells, as carbon fines were responsible for clogging (Environmental Science and Engineering, Inc. 1988). However, some studies on recharging effluent to impede saltwater intrusion suggested that rather large amounts of suspended solids could be tolerated without clogging (Laverty et al. 1961).

6. Particles that are not removed in the postfilter system and pass the recharge well screens will cause some clogging of the aquifer. Particles that are deposited in the immediate vicinity of the recharge well are expected to reduce the well's recharge rate the most. Smaller particles are expected to be carried deeper into the aquifer than larger particles; therefore, their impact on reducing the well's recharge rate is expected to be less when compared with that of the larger particles. Microbial fouling may complicate the above generalizations, as microbes are expected to attach to the carbon particles and increase the particle's effective size. If microbes attach preferentially to small particles, then the clogging effect of the small particles would be enhanced. Particle binding can be electrostatic in nature because of charges associated with microbial produced glycocalyx (e.g., capsule, slime) (Costerton, Irvin, and Cheng 1981; Lewis and Gattie 1990).

7. Work by Jubboori, Stewart, and Adrian (1974) indicated that microbial growth could decrease recharge well capacity in models of recharge wells sometimes in as little as a few hours, especially when the recharge wells had resting periods. They found that short periods of recharge water containing 250 mg/ℓ of sodium hypochlorite caused the recharge rate to increase dramatically, apparently because of the germicidal effect of the oxidizer on the microbial populations.

8. Kawanishi et al. (1990), using small soil columns, concluded that excessive microbial growth within the soil matrix could significantly impact soil hydraulic conductivity by as much as two orders of magnitude in as little as 40 days. They further concluded that the amount of substrate in the permeant did not impact the rate and density of biological growth in soil systems.

9. Ghiorse (1986) evaluated the composition and microbial type association of sheathing bacteria. He summarized that cation-based oxides produced by various bacterial groups can result in significant masses of extracellular materials that can significantly impact plugging of porous media.

10. Research suggests that *Pseudomonas* secretes a sticky slime that builds up on pipe interiors. This creates a continuous reservoir of microorganisms that could contaminate water flowing through pipes (Fackelmann 1990). Bacteria generally do not move large distances in fine-textured soil (less than a few meters, for example); but they can migrate much larger distances in coarse-textured or fractured materials (Bitton and Marshall 1980). Bacterial growth that coats the gravel in the packing material may slough off and be carried farther out in the packing material where it may accumulate and eventually cause fouling.

11. Active microbial systems require the presence of four primary environmental factors (Zappi et al. 1991). These factors are the presence of appropriate microbial types, food sources, electron acceptors, and nutrients. Natural soils systems typically contain numerous populations of native bacteria that are capable of existing in saturated aquifers (Alexander 1977). Other potential sources of bacteria that may contribute to excessive microbial growth in recharge wells are populations growing within activated carbon adsorbers that detach from the activated carbon particles within the adsorber and are transported via the effluent into the well. Activated carbon adsorbers provide ideal conditions for growth of high populations of microbes that are acclimated to the site contaminants (Kim and Pirbazari 1989). In some

cases, microbial metabolic activity is high enough to result in the regeneration of spent adsorption sites (Goeddertz, Matsumoto, and Weber 1988).

12. Food sources for microbial populations growing within recharge systems are the contaminants either flowing by the microbial colonies or adsorbed onto carbon fines migrating into the wells from the treatment system. Contaminants flowing by microbial colonies are capable of assimilation into the cell capsules within short periods of water-microbe contact. Contact stabilization is a biotreatment process that uses this phenomenon for treatment of contaminated waters (Metcalf and Eddy, Inc. 1979). Microbes are also capable of using adsorbed contaminants as food sources (Schultz and Keinath 1984; Kim and Pirbazari 1989).

13. Growth of microbial populations within activated carbon adsorbers without the benefit of nutrient addition has been documented (Faust and Aly 1987). Potential nutrient sources for microbial populations within well systems are available from nutrients leached into the groundwater from the aquifer soils. All forms of microbial activity require the presence of an electron acceptor required for the maintenance and synthesis of cell mass. Aerobic biodegradation requires the presence of oxygen as an electron acceptor. Anaerobic degradation occurs without the presence of oxygen but instead uses inorganic compounds such as nitrates and iron complexes as electron acceptors (Zappi et al. 1991). The type and extent of biological activity occurring within recharge wells is dependent on the fate of the groundwater within the treatment system. If the influent or effluent is allowed appreciable contact time with oxygen-containing gases such as air, then aerobic degradation is possible. On the other hand, if alternate electron acceptors such as nitrates are present in the effluent and oxygen is not present, then anaerobic degradation will proceed within the wells if the other environmental factors are present.

Objectives

14. The overall objective of the three tasks was to determine which factors, both operational and natural in nature, were or will be responsible for reductions of recharge capacity at the NBS. Individual objectives of each task are discussed below.

a. Fate of carbon fines at the pre-IRA NBS. The objectives of the fate of carbon fines at the pre-IRA NBS were to: (1) identify the source(s) of carbon fines in the recharge wells, (2) evaluate solids-removal equipment at the pre-IRA NBS, and (3) identify alternatives to improve solids-removal efficiency.

b. Reduced recharge well capacity. The objective of this task was to assess potential causes of reduced recharge well capacity.

c. Reduced recharge trench capacity. The objective of this task was to assess the potential for excessive microbial growth that potentially may reduce the recharge capacity of the newly installed recharge trenches.

Study Approach

Fate of carbon fines at the pre-IRA NBS

15. Observing the system and the standard operating and maintenance (O&M) procedures used by RMA personnel was necessary to accomplish the above stated objectives for this task. WES engineers and scientists visited the RMA NBS and interviewed plant personnel to obtain information concerning the O&M procedures and probable causes of recharge capacity reductions. During this visit, water samples were collected at various locations throughout the NBS. These samples were used to determine if standard analytical techniques could be used to measure carbon fines concentrations for the NBS.

16. To determine the magnitude and amount of carbon fines migrating into the recharge wells, a mass flux analysis of suspended solids throughout the NBS was performed. The mass flux analysis is described in detail in Part II. All suspended solids concentrations measured during mass flux analysis were assumed to be carbon fines. Carbon mass flux pathways through the NBS were determined by using suspended solids concentration as a direct indicator of carbon fines concentrations.

17. Solids-removal assessment was based on results from the mass flux analysis and on observations made during various field trips. The results of this assessment are presented and discussed in Part III of this report.

Reduced recharge well capacity

18. Potential microbial fouling of the recharge wells was investigated by collecting water samples from eight recharge wells for microbial enumeration. The samples were collected by personnel from WES and personnel from the University of Mississippi working under contract with the WES. Samples were

analyzed for pH, reduction/oxidation (redox) potential, microbial enumeration, and bacterial group identification.

Reduced recharge trench capacity

19. Potential microbial fouling of the recharge trenches was examined by the collection of water samples from the recharge trenches piezometer tubes. The samples were collected by personnel from WES and personnel working under contract with WES. The samples were analyzed for pH, conductivity, salinity, temperature, nutrients, metals, and microbial enumeration.

System Configuration

20. A process flowchart for the pre-IRA NBS is shown in Figure 1. Figure 2 illustrates the carbon flow and water flow paths at the pre-IRA NBS. Organic contaminants in the groundwater are removed using activated carbon. The activated carbon adsorption system is configured with three pulsed-bed adsorbers. At the time this study was conducted, the influent to the adsorbers was passed through a system of 100-μm cartridge prefilters. The effluent from the three adsorbers was composited in a common effluent piping manifold, then filtered through the posttreatment filters consisting of a 10-μm bag and cartridge filters. The treated water was collected in an effluent sump before distribution to 38 recharge wells and 15 gravel-packed recharge trenches.

21. In FY89, the NBS was reconfigured as part of the IRA undertaken by the PMRMA and Shell Chemical. Therefore, during performance of the three annual enumeration efforts of microbial populations in the recharge trenches (FY89-FY91), the NBS had already been modified as part of the IRA. As part of the IRA, a common influent was used for all three absorbers by conversion of the three-manifold influent system into a common line. Also, all cartridge filters were replaced with bag filters. Finally, 10 gravel-filled trenches were installed in 1988; and an additional 5 gravel-filled trenches were installed in 1990. The trenches were installed as part of the IRA to improve the capacity for recharging the treated groundwater. An implementation document (RIC 89139R01) is on file at the Rocky Information Center (RIC). The description of the system and its start-up performance is summarized in Lutton (1989).

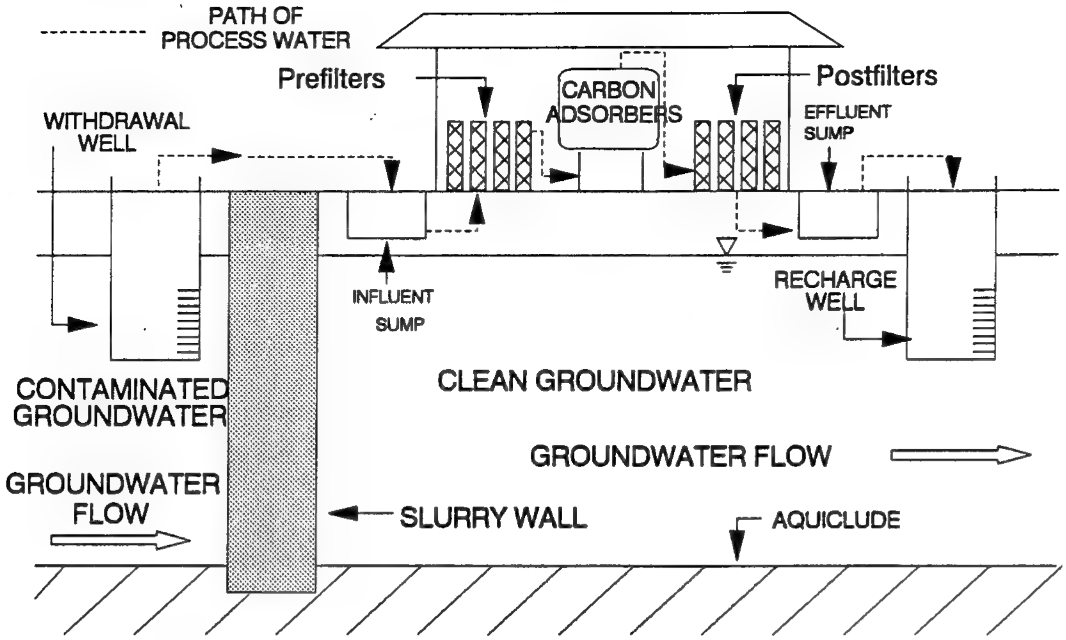

Figure 1. Definition sketch, North Boundary Treatment System, path of process water

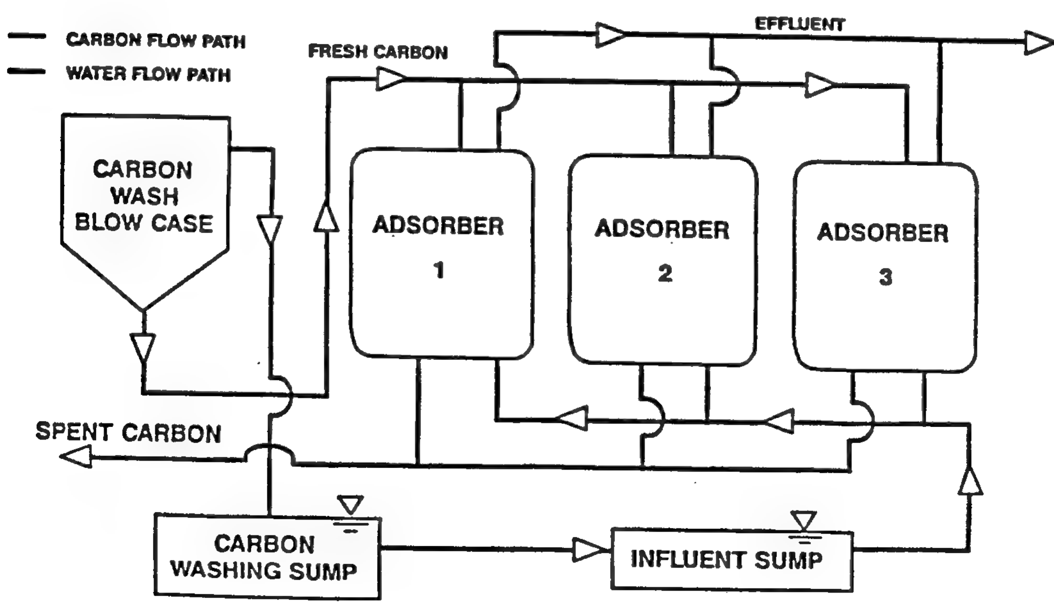

Figure 2. Definition sketch, North Boundary Treatment System, carbon flow and water paths

22. The design consists of gravel-filled trenches penetrating into the alluvial aquifer stratum. Recharge water is fed longitudinally through a perforated plastic pipe near the top of the gravel interval. A filter fabric sheet separates the gravel interval from silty soil placed to the surface as backfill above.

PART II: MATERIALS AND METHODS

Suspended Solids Analysis

23. Samples for mass flux analysis were collected by WES personnel during the period of September 13-23, 1988, at various locations throughout the NBS. These sampling points are listed in Table 1, along with the number and frequency of the samples collected at each location.

24. Suspended solids samples were collected in 1-gal* plastic jugs with plastic caps. Samples were transported by WES personnel to WES for suspended solids analysis. The samples were stored at room temperature until analyzed for suspended solids concentrations. All filtrate (water) was returned to the NBS upon completion of suspended solids analysis.

25. Suspended solids analysis was performed according to the procedures described in Standard Methods For the Examination of Water and Wastewater (American Water Works Association 1985). Millipore type HA filter pads with a nominal pore size of 0.45 μm were used during filtration of suspended solids samples. Suspended solids analyses were performed using at least three replicates. Weight determinations were made using a Sartorius Model 195917 analytical balance with a 0.00001-g minimum scale capability. Based on balance accuracy and statistical evaluation of the suspended solids data, a test accuracy of 0.5 mg/ℓ was used for evaluating mass flux data. Suspended solids values less than 0.5 mg/ℓ were assigned a suspended solids concentration of 0.0 mg/ℓ.

Particle Size Determination and Distribution

26. Particle size analysis was conducted by Particle Data Laboratories (PDL) LTD., Elmhurst, Illinois. Six samples were sent to PDL for analysis. These samples included a carbon wash rinse water collected approximately 5 min into carbon wash activities, a sample of the floor drain input to the floor drain sump during carbon change activities, a sample of the input from the floor drain sump to sump A, two samples from the bottom of the effluent sump, and a sample of carbon fines collected from the in-line Y-screen at Well 21.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 4.

Upon completion of particle size analysis by PDL, the samples were returned to WES for later disposal at the NBS, RMA.

27. The analytical technique used by PDL known as electrozone particle counting measures the difference between the electroconductivity of water and carbon to determine particle sizes and distribution (see Appendix A for details). Water containing the carbon fines is passed through an orifice in which an electrical field exists across the orifice plate opening. The change in electrical potential is recorded as each particle passes through the orifice. Any change in potential correlates to a respective particle size. The output of an electrozone unit is a series of pulses that are electronically amplified, scaled, and counted.

28. There are two methods of presenting fine particle size analysis data. One method is based on the frequency distribution of the particle sizes. This method of data presentation is analogous to counting and sizing each particle under observation with a microscope. The second method of data presentation is mass distribution. Mass distribution is analogous to weighing and sizing the particles retained on a sieve. The data from PDL are presented using both methods.

Microbiological Sampling of Recharge Wells

29. To determine the potential for fouling of recharge wells, water samples were collected from eight recharge wells by WES personnel during the week of December 12, 1988. Water samples were collected from recharge Wells 1, 3, 5, 17, 19, 24, and 26. Water samples were collected at depths of 3 and 15 ft (measured from the top of the well cavity). Samples from various depths were collected from each well to determine if stratified populations of various microbes existed in the NBS recharge wells. Well 5 had a piezometric level of approximately 10 ft below the surface (as measured from the top of the tube); therefore, only one sample was collected at a depth of 15 ft. Samples were analyzed immediately for pH and by WES personnel using a portable Fisher Model 955 pH meter and Fisher Brand probes. Samples were prepared in the field for bacteriological enumeration and identification at the University of Mississippi Biological Laboratories in Oxford, Mississippi. Bacteriological identification and enumeration procedures are described in Appendix B.

Microbiological Sampling of Recharge Trenches

30. In 1989, Trenches 3, 5, and 7 of the 10 trenches were evaluated for microbial fouling. In 1990, all 10 of the trenches were evaluated for microbial fouling. Five new trenches (11-15) were installed in 1991. The 1991 and 1992 sampling effort was expanded to include all 15 trenches of the NBS. Water samples from all of the trenches were collected from the middle of the piezometer tubes water column. Samples were analyzed in the field for pH using a Fisher Model 107 Portable pH Meter. Temperature, conductivity, and salinity were evaluated using a YSI Model 33 Portable Conductivity/Salinity Meter with a S-C-T probe. The dissolved oxygen content of the water in the piezometer tubes was measured using a YSI Model 57 Dissolved Oxygen Meter. Samples for nutrients and metals were collected and preserved in the field. Chemical analysis of the samples was performed by the Analytical Laboratory Group at WES. Samples for bacteriological enumeration and identification were prepared in the field. Inoculated media were returned to WES for incubation, enumeration, and identification.

PART III: RESULTS

Mass Flux Analysis

31. Tables 2-9 present a summary of the mass flux results for each major solids removal and treatment unit at the NBS. Unreduced suspended solids analytical data are presented in Appendix C. Each table lists the date, sample time, cumulative time, influent and effluent suspended solids concentrations, and the average influent and effluent suspended solids concentrations along with the respective standard deviation associated with each average value. Variability in the number of samples collected is due to the uncertainty of the amount and frequency of sample collection required to completely characterize the solids flux through the NBS. Cumulative time represents the accumulated time (in hours) that had elapsed from the initiation of the field study to the collection of the sample.

32. Figure 3 presents cumulative time versus suspended solids concentrations for prefilter A influent and effluent and plant effluent. At the beginning of the study, water from the floor drain sump, which is high in solids concentration, was pumped into sump A to lower the water level in the floor drain sump. The appropriate water level in the floor drain sump is maintained by periodically pumping water into sump A. Although a makeshift bag filter was located at this input, considerable overflow around the bag filter and into the sump was observed by WES personnel.

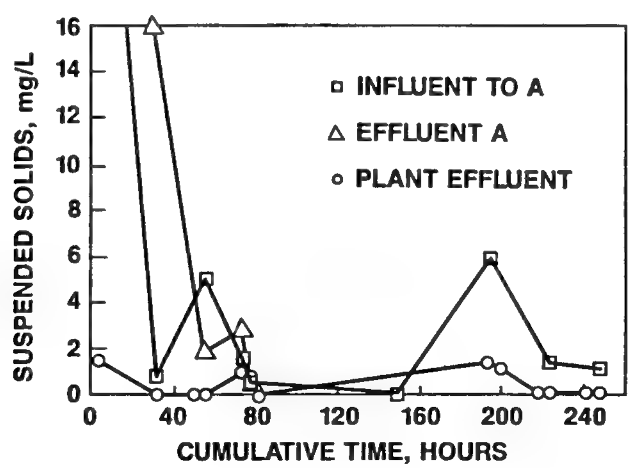

Figure 3. Suspended solids versus time for prefilter A and NBS plant effluent

33. Figure 3 indicates a high solids loading on the NBS prefilters because of the input of water from the floor drain sump. A water sample from the water flowing into sump A from the floor drain sump was collected near the termination of floor drain sump pump-down activities. This sample had a suspended solids concentration of approximately 38 mg/ℓ. Since the floor drain sump is essentially quiescent, with little or no flow, the suspended solids within the sump are allowed to settle to the bottom. Therefore, the initial suspended solids concentration in water from the floor drain sump probably was significantly higher because the water is pumped into sump A using a submersible pump, which is located on the sump bottom. It is evident that a high solids loading on the prefilters affects system effluent.

34. The reason for the peak plant effluent suspended solids concentration at 200 hr in Figure 3 is not known. During this period, a load of fresh carbon was washed and pulsed into adsorber B. One possible reason for the peak at 200 hr could be that the carbon washing and transfer operations interrupt total system flow, which in some way impacts solids-removal efficiency. Another possible reason for the peak at 200 hr could be that carbon fines trapped on the prefilters, which are 100-μm spiral-wound cartridge filters, are forced through the spiral windings by the momentum forces of the flowing water while the filters are in operation. Transport of carbon fines through the filter weaving was observed by WES and PMRMA personnel during an inspection of spent cartridges from NBS filters.

35. Figure 4 presents the time variation of suspended solids concentrations for adsorbers A, B, and C effluents. The effluent suspended solids concentrations from the adsorbers were all less than 2.0 mg/ℓ throughout the course of the sampling effort except during the initial stages of the mass flux sampling. The peak in Figure 4 is similar to the peak in Figure 3. This point represents the period when water from the floor drain sump water was pumped into sump A, indicating that high solid loadings were carried throughout the system and ultimately affected plant effluent suspended solids concentration. These data show that carbon washing activities directly impacts the solids loading on the postfilter system as well as plant effluent. After washing loads of fresh carbon for adsorbers A or B, the effluent from the adsorber receiving the fresh carbon and the plant effluent showed suspended solids concentrations that were elevated relative to normal operations. This indicates that incomplete carbon washing is occurring along with carbon fines generation during transfer operations. This increase in absorber and plant

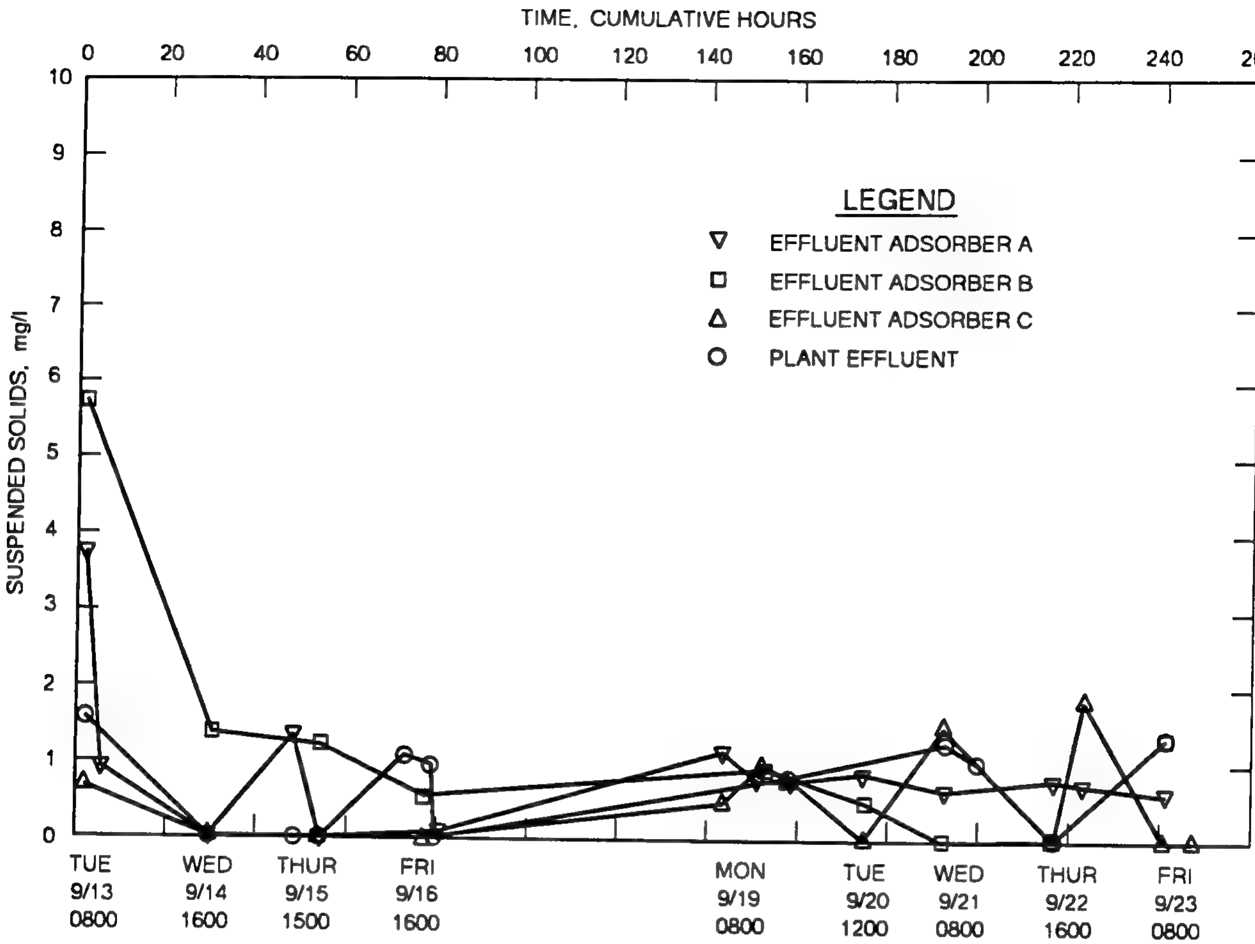

Figure 4. NBS effluent and adsorbers A, B, and C effluent

effluent concentrations is evident in Figure 4. Adsorber A had fresh carbon added at approximately 20 hr, while absorber B had fresh carbon added at approximately 190 hr.

36. Average influent and effluent suspended solids concentrations were calculated along with the respective standard deviations for the prefilters, adsorbers, postfilters, and the NBS plant effluent. These data are presented in Table 10. The prefilters had an 86-percent solids removal efficiency.

37. The high standard deviations listed in Table 10 for influents to the prefilters indicate a wide range in suspended solids concentrations. When solids loadings on the prefilters were high, the effluent suspended solids concentrations were as high or higher than the respective influent concentrations. This condition is best illustrated in a plot of suspended solids concentrations versus time in cumulative hours for prefilter A influent and

effluent (Figure 5). At 30 hr, the effluent suspended solids concentration is approximately 16 times that of the time respective influent concentration. The effluent suspended solids concentration is also greater at approximately 75 hr. One explanation for these two events is that trapped solids on the filter cartridge surface migrate through the spiral weaving of the cartridge filter to the filtrate. The data in Figure 6 is an expanded plot of Figure 5, which includes all the prefilter A samples collected during the field study. The data in Figure 5, show that after the initial high loadings, the influent suspended solids concentrations were higher than the effluent concentrations, indicating that under lower solids loadings, the prefilters functioned properly.

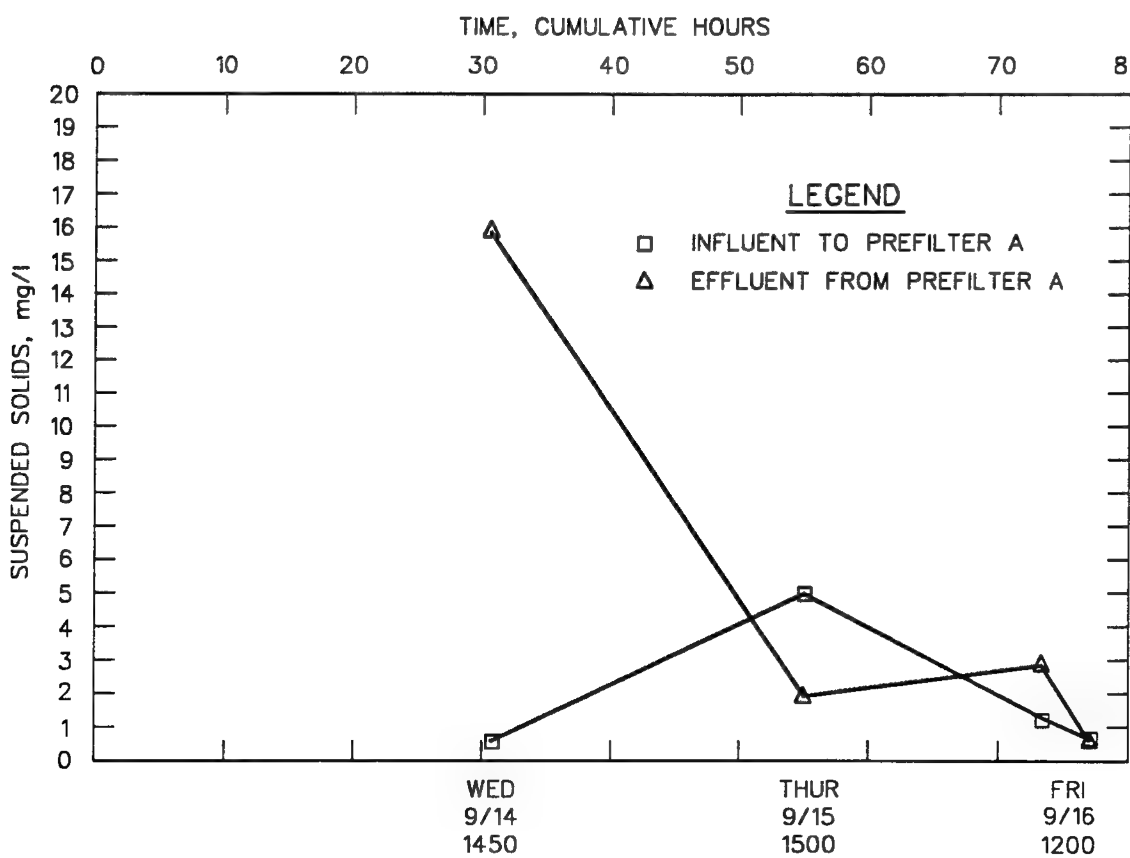

Figure 5. Suspended solids concentrations versus time for prefilter A influent and effluent

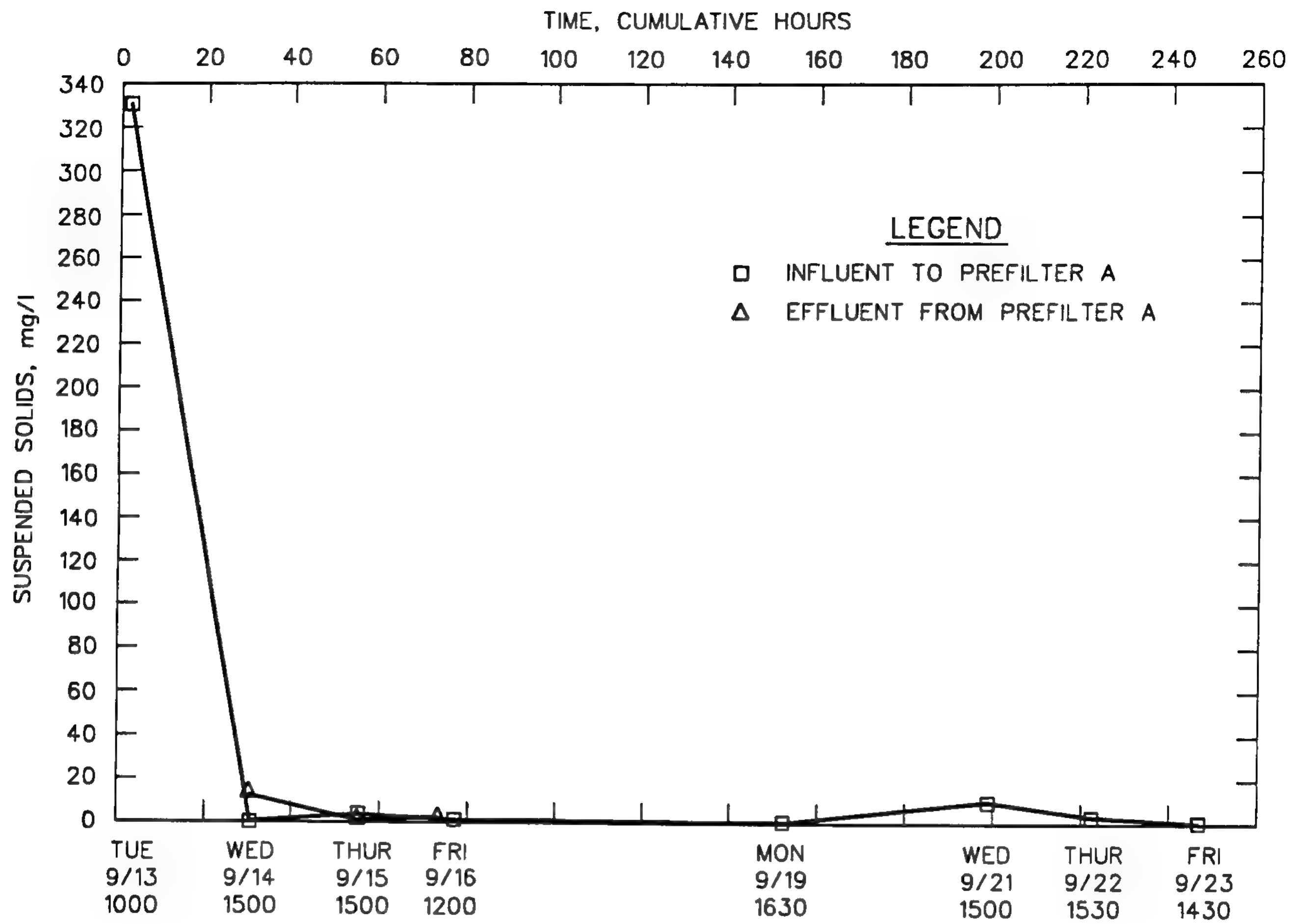

Figure 6. Suspended solids concentration versus time for prefilter A influent and effluent (expanded plot)

38. The average effluent suspended solids concentrations for adsorbers A and C were higher than the average influent concentration for adsorber B. These values indicate that carbon fines trapped in the fresh carbon at the top of the adsorbers are leaving with the adsorber effluent. The data were inconclusive regarding the fate of suspended solids in the adsorbers and whether or not the adsorbers were a source of suspended solids. The data show, however, that some carbon fines are being transported to the postfilters in the adsorber effluent. The mass flux data presented in Figure 4 for adsorbers A and B indicate that suspended solids concentrations were greater initially when fresh carbon was added to the adsorbers.

39. Postfilter performance (see Table 10) was evaluated by collecting effluent samples from the discharge into the NBS effluent sump. Postfilter influent suspended solids concentrations were calculated using a flow-weighted

average of the three average adsorber effluent concentrations. The post-filters removed approximately 58 percent of the solids from the influent.

40. Figure 7 presents suspended solids concentrations versus time in cumulative hours for the NBS effluent. From Table 10, the average effluent suspended solids concentration was 0.5 mg/ℓ with a standard deviation of 0.6 mg/ℓ. The high standard deviation associated with average NBS effluent suspended solids concentration is due to the three peaks found in Figure 7. During this study, the NBS effluent suspended solids concentrations were less than 0.5 mg/ℓ, the study analytical detection limit for suspended solids. The first peak in Figure 7 at the beginning of the study was due to carbon fines input into sump A from the floor drain sump. The other two peaks coincide with carbon transfer operations for adsorbers A and B.

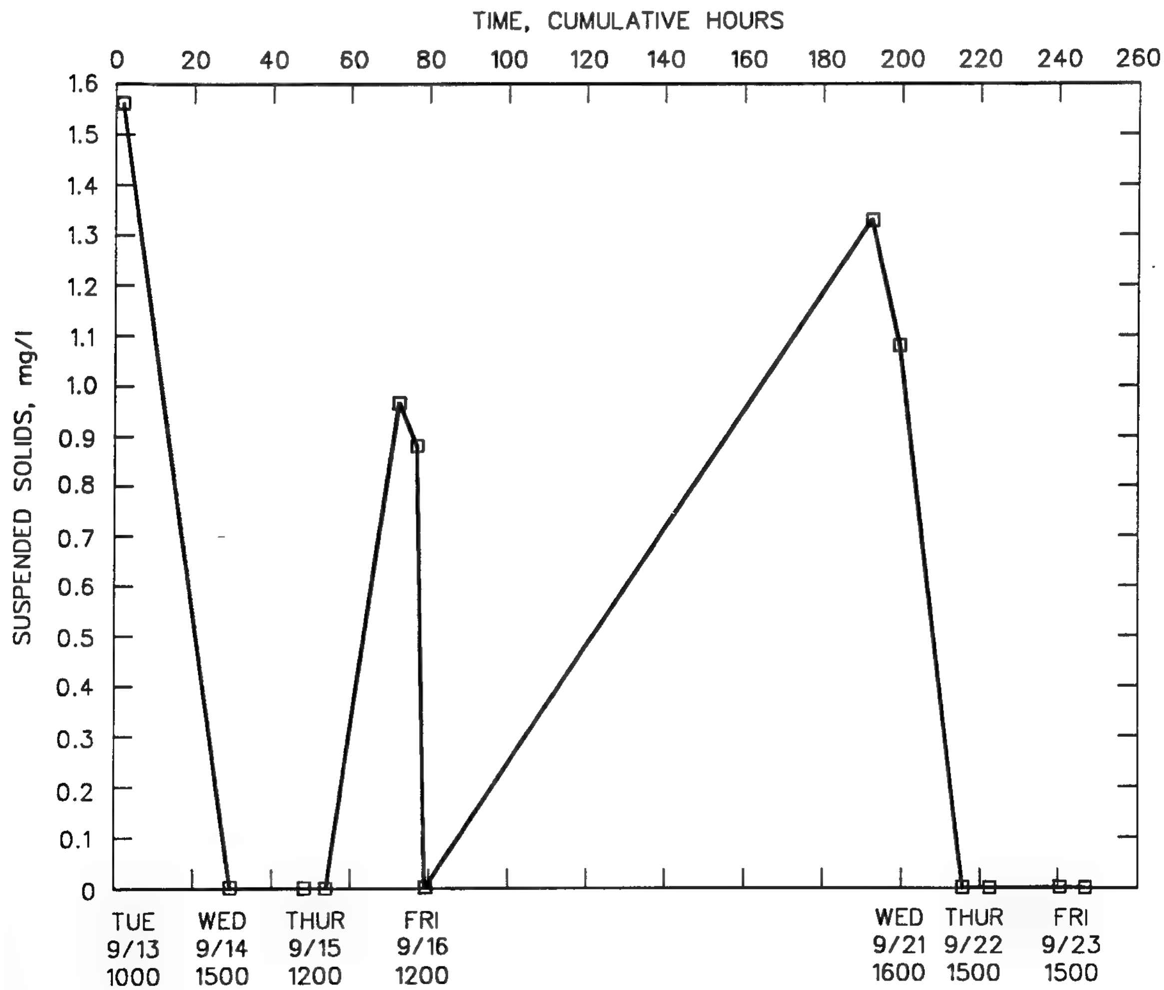

Figure 7. Suspended solids concentration versus time for NBS plant effluent

41. Carbon washing activities at the NBS are considered complete when the rinse water from the blow case runoff pipe does not contain carbon fines that can be visually observed by the plant operators. WES personnel collected samples of blow case rinse water after it was considered "clean" by the operators. A suspended solids concentration of approximately 22 mg/ℓ was detected in the "clean" rinse water. On one occasion during the study, the operators visually inspected the rinse water inside the facility, which has relatively poor lighting. Visual inspection of the same rinse water sample in bright sunlight showed carbon fines still present in the sample. This incomplete carbon washing allows carbon fines to be transferred to the adsorbers undetected. Use of a multi-probe, in-line turbidimeter may eliminate problems associated with incomplete washing of the fresh carbon. Set time sequences for carbon washing may not completely remove carbon fines if a fresh batch of carbon has unusually high amounts of carbon fines.

42. Carbon fines were not detected in the input to any of the recharge wells sampled during the study. The NBS sumps were cleaned in 1986; however, carbon fines were observed in all of the sumps at the NBS during the sampling effort. The effluent sump had surprisingly high suspended solids concentrations of 229 mg/ℓ on September 15, 1988, and 2,192 mg/ℓ on September 23, 1988. These samples were collected from the bottom of the sump using a standard 3-ft-long well bailer. The concentrations of carbon fines in the other sumps were not measured, but carbon fines were found to be present on the bottom of the sumps by observing water samples collected from the sump bottoms with the well bailer.

43. Based on an effluent suspended solids concentration of 0.5 mg/ℓ and a total system flow rate of 230 gpm, the average annual solids loading to each of the 38 recharge wells is approximately 13.5 lb/year (NOTE: 0.5 mg/ℓ effluent solids concentration is high, indicating that the 13.5 lb/year is conservatively high). Although conservatively high, this is approximately half the estimated loading reported in Task 36 (Environmental Science and Engineering, Inc. 1988). The impact of carbon fines on recharge well packings and the surrounding aquifer of this solids loading is unclear. Therefore, suspended solids plugging of the well packing and the aquifer must be considered as contributing to the problem of reduced recharge capacity at the NBS.

Particle Size Analysis

44. Results of particle size analysis on the six samples analyzed by PDL are presented in Table 11. The unreduced data as well as a description of the analytical procedures used by PDL are presented in Appendix A. Table 11 presents statistics for the particles on a mass (or volume) basis and on a frequency (or population) basis. A few large particles can have as much mass as a large number of small particles. Therefore, the size of a particle on a mass basis data presentation (whether measured as the geometric mean diameter, the median diameter, or the modal diameter) will be larger than the correspon-ding sizes measured on a frequency basis data presentation. The single size that presents the most information about the sample is the arithmetic mean diameter. The following discussion will refer to the arithmetic diameter when mention is made of particle size.

45. The most important statistics from the viewpoint of aquifer clog-ging are the particle sizes in the effluent sump and at the recharge well screens. The two samples taken on September 15 and 23, 1988, from the bottom of the effluent sump had arithmetic mean diameters of 10.80 μm and 2.42 μm, respectively. The recharge well screen sample showed an arithmetic mean par-ticle size of 11.48 μm on a frequency basis. Thus, a large number of rela-tively large particles are escaping through the postfilters.

46. Particles that are not removed in the postfilter system and that pass the recharge well screens will cause some clogging of the aquifer. Par-ticles that are deposited in the immediate vicinity of the recharge well are expected to reduce the well's recharge rate the most. Smaller particles are expected to be carried deeper into the aquifer than larger particles; there-fore, their impact on reducing the well's recharge rate is expected to be reduced when compared with that of the larger particles. However, biological fouling may complicate the above generalizations, as microbes can attach to the carbon particles and increase the particles's effective size. If microbes attach preferentially to small particles, then the clogging effect of the small particles would be enhanced. Increased growth on or around carbon par-ticles is possible because carbon adsorbs organic contaminants, thus providing concentrated food sources for growth. This increased availability of food source can add to the potential for fouling.

47. The particle size analysis data for samples collected during the carbon wash activities when presented on a frequency basis indicate that most

of the carbon fines generated during carbon washing activities are less than 1.0 μm. A 5.0-μm filter is the minimal filter size that can be efficiently operated at the plant flow rate. This strengthens the conclusion that the connection between the floor drain sump and sump A should be eliminated. The sample taken from the carbon wash blowcase rinse water had extremely small particles when viewed from a frequency basis, but easily removable particles using a 5-μm filter based on the mass basis presentation. Both reporting methods indicate that the input to the floor drain sump from the floor drains contain relatively large particles of carbon fines. These data do indicate possible success in removing a high percentage of the carbon fines from the waste stream into the flow drain sump. Particle input into sump A is relatively consistently sized. Therefore, a 5-μm filter would effectively remove a high percentage of the solids.

48. It was assumed that a 5- and 10-μm filter would remove all particles having a diameter greater than the respective pore sizes of each filter. The results indicate that a 10-μm filter would remove a large percent of the carbon fines mass but a relatively small percent of the total number of particles. A 5-μm filter would remove a large mass of particles and a rather variable number of particles depending upon which process stream is evaluated. Based on the mass basis particle data, the most difficult particles to remove are the carbon wash activity input to the floor drains and input to sump A from the floor drain sump. The 5-μm filter will remove in excess of 68 percent of carbon fines mass in the floor drain sump water versus 25 percent for the 10-μm filter. On a mass basis, the 10-μm filter would perform approximately the same for removing carbon fines from the other five samples as a 5-μm filter, because removal efficiencies for the 5- and 10-μm filters do not vary greatly except for the input stream to sump A from the floor drain sump. The mass basis of data presentation is skewed toward the larger carbon fines, thus, indicating relatively high removal percentages for both filter pore sizes. On a frequency basis, it is apparent that a 5-μm filter would be much more effective than a 10-μm filter for removing carbon fines in all of the samples. Based on a frequency basis of data presentation, the 5-μm filter would remove an average of 16 percent more carbon fines than the 10-μm filter. Sixteen percent of carbon fines based on frequency analysis is a substantial number of carbon fines. Therefore, the conversion of the filter systems to 5-μm effective pore size could significantly reduce the amount of carbon migrating through the NBS.

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49. The recharge well water samples had an average pH of 7.7, which is considered a near neutral Ph. This Ph value is within a range most conducive to microbial growth. The average redox potential was +153 Mv indicating a mildly reduced water. This redox potential is reasonable in that the water taken from the dewatering wells is borderline aerobic because of limited contact with the atmosphere while in the influent and effluent sumps.

50. Microbiological results show some fungal growth in the recharge wells sampled. The fungi were enumerated using simple enumeration methods for general indication of fungi presence and not precise enumeration; however, rough estimates indicate that they are sufficiently abundant to pose potential well fouling problems. This conclusion is based on previous experience with pressure relief wells along levees of flood control systems operated by the US Army Corps of Engineers.

51. Heterotrophic aerotolerant bacteria were found in all wells sampled (Figure 8). Heterotrophic bacteria are indicative of wells with relatively low organic content and may add to the biofouling of the recharge wells. The range of heterotrophic bacteria is within the "expected" range of populations found in most groundwater wells. The population levels observed in the NBS recharge well samples are considered too low to cause significant recharge well capacity reductions.

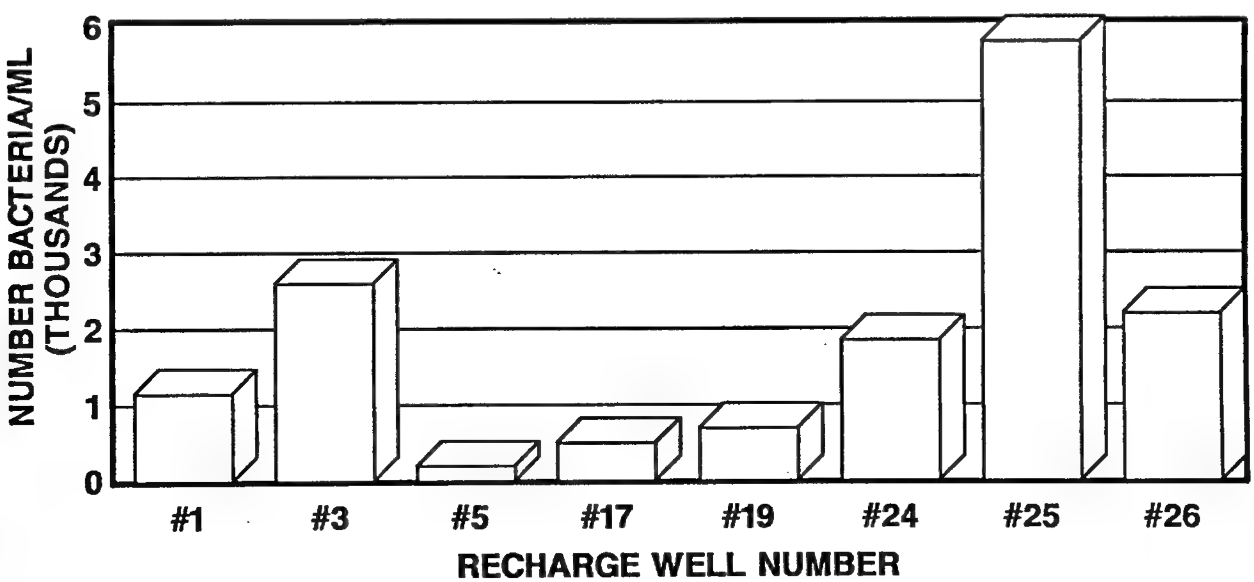

Figure 8. Average heterotrophic bacteria population found in each well

52. Very large populations of facultative bacteria were found in all the wells sampled except Well 17 (Figure 9). Well 17 also had relatively small populations of the other microorganisms sampled (see Figures 8 and 10). Facultative bacteria are typically found in wells receiving water of high organic content. In contrast to the level of heterotrophic aerotolerants enumerated in the wells, the number of facultative bacteria are considered extremely high. This indicates a very high potential for well clogging because of biofouling with these organisms.

53. Extremely high populations of fermenters were detected in Well 3, while somewhat lower levels were observed in Wells 1, 24, 25, and 26 (Figure 10). Fermenters are part of the facultative class of microbes, but differ from the other facultative types because of their characteristic acidic by-products and slime production. In addition to the highest level of fermenters measured, Well 3 also has one of the lowest recharge capacities of the NBS recharge wells.

Bacteriological Enumeration Limitations

54. Several factors are to be considered when determining the effects that various levels of populations have on the recharge capacity of groundwater wells. One such factor is bacteria type. The water samples collected were used to enumerate and identify only certain general bacteriological groups. However, these groups do not include all possible types of bacteria

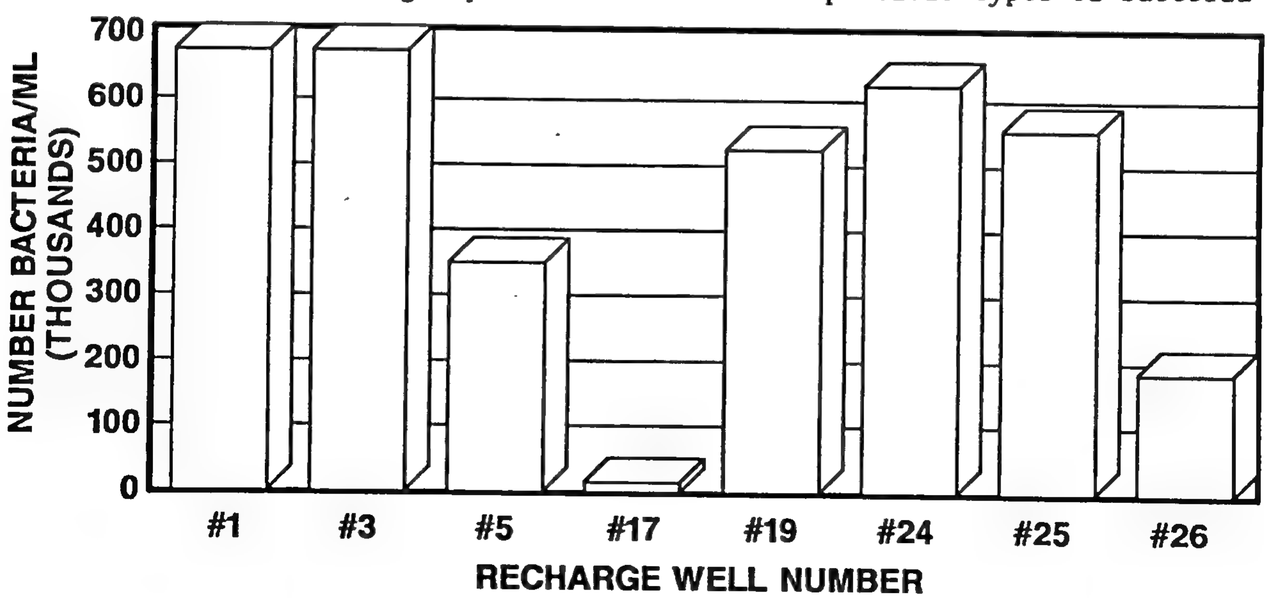

Figure 9. Average facultative population found in each well

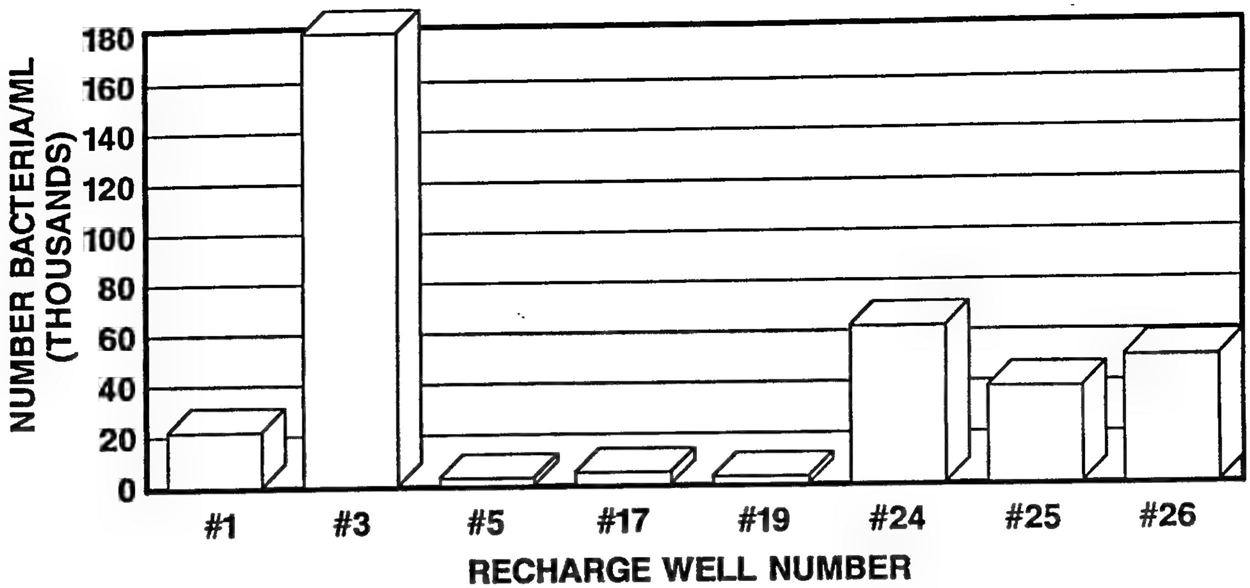

Figure 10. Average fermenter population found in each well

that can be found in soil-aquifer environments. Other bacteriological types, such as iron-reducing bacteria, could be present. Since iron-reducing bacteria are very difficult to culture under laboratory conditions, enumeration and identification of iron reducers were not attempted during this phase of study. Another factor to consider is that each bacterial cell typically produces 500 times its cell volume of slime material (Lehr and Hackett 1985). If bacteriological populations multiply, slime generation increases and the recharge capacity of a system of wells decreases significantly because of increased clogging by the slime by-products in the pore spaces surrounding the well packings.

55. The final factor pertinent to evaluating population data is that the samples collected during this study were water samples and not soil samples. Water-borne bacteria represent only a small portion of the total amount of microbes surrounding a well screen and packing. A large percentage, if not a majority, of the microorganisms present are likely adsorbed to the solid materials surrounding the well. The reported population estimates are thus quite conservative, and actual soil populations are expected to be significantly higher.

56. Figure 11 presents the average amount of water recharged through each well weekly from the period of August 3, 1988, to November 2, 1988 (NOTE: the data from the week of October 12 was not included in the calculation of these averages because of incomplete data for that week). Average weekly volumes of recharge water received by each of the NBS recharge wells are

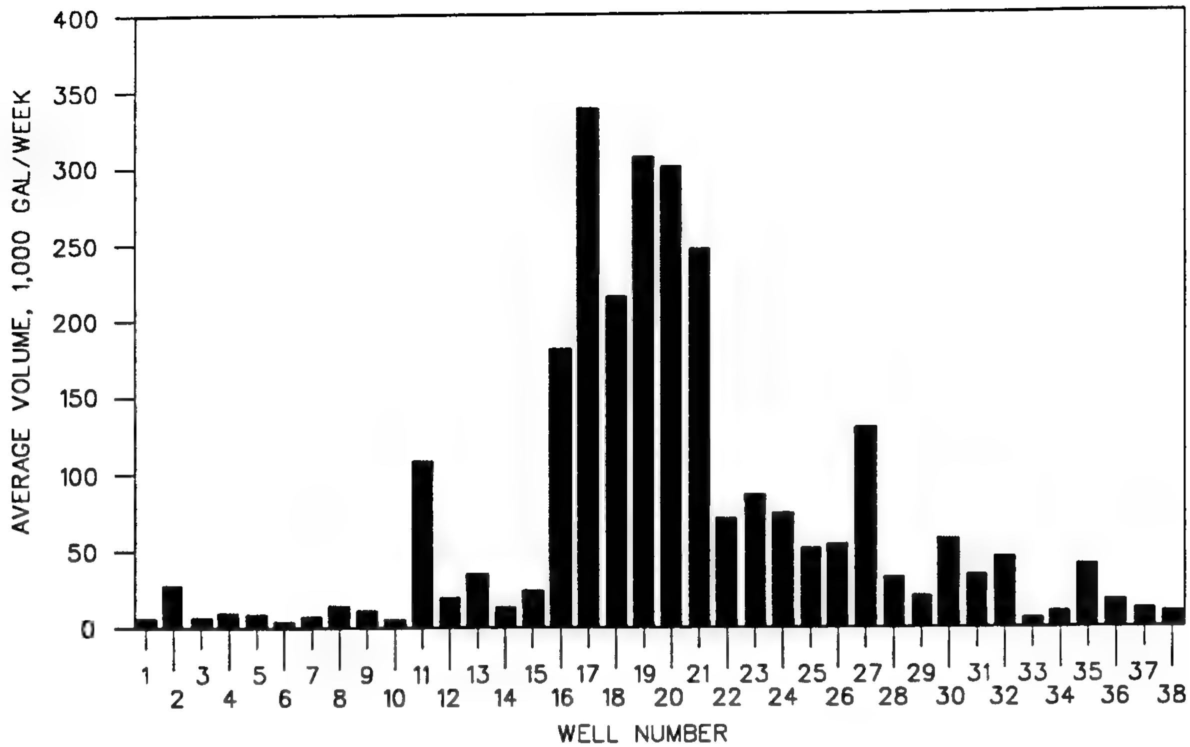

Figure 11. North Boundary System recharge wells, average weekly recharged water volumes

presented in Appendix D for informational purposes. Figure 11 reveals that Wells 16-21 are wells receiving the highest volumes of recharge water. Well 17 receives the highest volume, with Well 19 being the second.

57. Figure 12 presents the bacterial populations for wells sampled for analysis and average weekly volume of recharge water along with facultative populations for each well sampled for enumeration and identification. Well 17 had no appreciable amount of microbes and had the highest recharge volume. Conversely, Wells 1 and 3 had the highest populations and the lowest amount of water recharged. The relationship between population and well recharge capacity is consistent for all wells sampled except for Well 19, which had a relatively high population with high recharge capacity. However, because longterm monitoring information is not available for these wells, it is not possible to determine whether the high population level in Well 19 is a transitory peak or an indication of a long-term trend. Differences in recharged water volumes could be associated with differences in microbial population levels; however, possible local differences in the porosity of aquifer soil types and/or location of the well screen in each of the wells may also have been important.

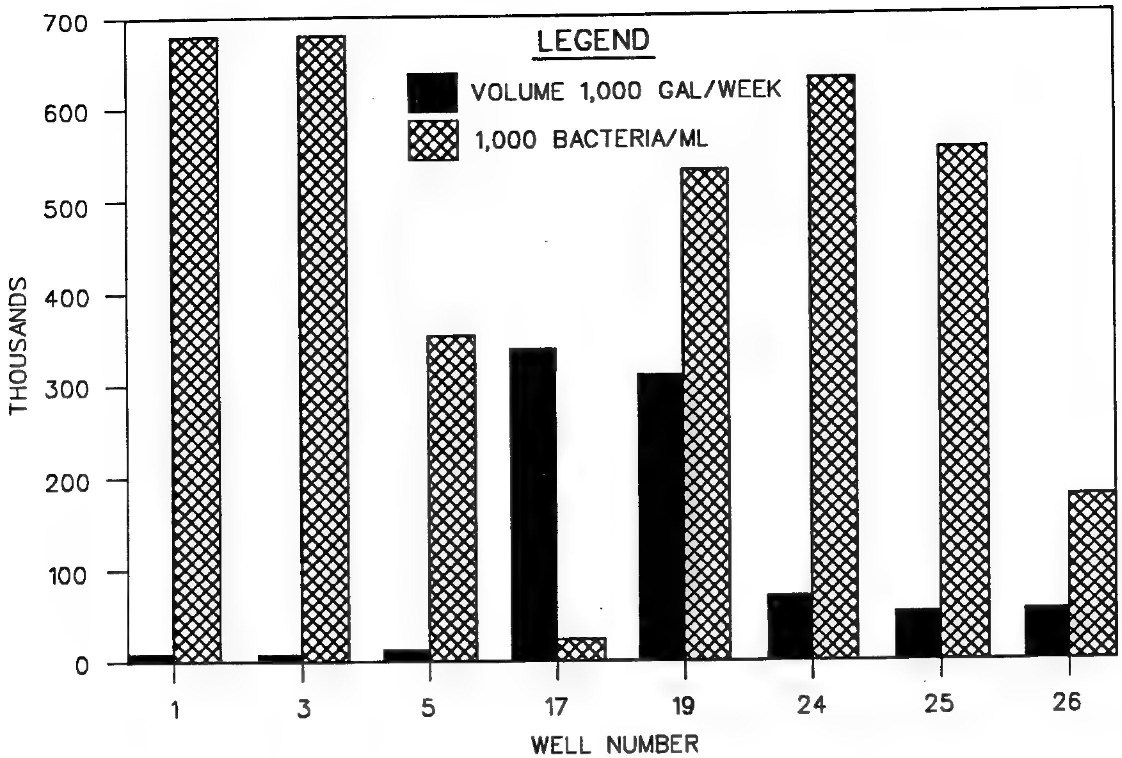

Figure 12. Average recharged water volumes per week and facultative bacteria populations for wells sampled for microbial analysis

Differences in aquifer soil types versus well screen locations were not evaluated in this study but should be examined in future investigations. Also, Well 19 is located next to the bog and is probably in hydraulic contact with the bog. Hydraulic contact reduces the hydraulic gradient (hydraulic gradient is head divided by length of travel) required to move a given quantity of water through the well.

Physical/Chemical Characteristics of Recharge Trenches

58. Physical and chemical data on the water collected from the trenches in 1990, 1991, and 1992 are summarized in Tables 12, 13, and 14, respectively. Water temperatures in the trenches remained relatively constant over the 3 years of sampling. The temperature ranged from 11 to 14 °C in 1990, 13 to 23 °C in 1991, and 14 to 22 °C in 1992. These temperatures are within the acceptable range supporting mesophilic to psychrophilic microbial growth. Although all the trenches were sampled in the summer months, little variation

in temperature is expected, because groundwater environments tend to maintain a consistent temperature in the 15 °C range.

59. The dissolved oxygen (DO) content in 1990 ranged from 1.7 mg/ℓ in Trench 1 to 4.9 mg/ℓ in Trench 2. All of the remaining trenches had very similar DO values, averaging 2.5 mg/ℓ. In 1991, the DO content of Trenches 11-15 ranged from 3.7 mg/ℓ in Trench 11 to 2.7 mg/ℓ in Trench 13. In 1992, the DO content ranged from 2.7 mg/ℓ in Trench 12 to 5.5 mg/ℓ in Trench 15. The DO values in Trenches 11-15 measured in 1991 and 1992 are very similar to those measured in Trenches 1-10 in 1990. The DO levels in Trenches 1-10 measured in 1991 and 1992 averaged much less than in 1990 (Table 15). This may be due to the addition of Trenches 11-15 at the NBS, which has diverted much of the flow into these trenches. The DO levels measured in the trench piezometer tubes in 1990, 1991, and 1992 are capable of supporting aerotolerant and facultative bacteria populations. Finally, the DO levels measured in the trench piezometer tubes in 1990, 1991, and 1992 compare with the oxidative conditions detected in the recharge wells in 1989, indicating similar oxidative conditions.

60. Adsorption of bacteria to surfaces is greatly affected by pH. The pH values for optimum adsorption depend on the relative isoelectric points of the microbial cells and the adsorbent. The strongest adsorption of bacterial cells generally occurs at a pH range of 3 to 6 (Bitton amd Marshall 1980). The pH of the water in the trenches measured during 1990, 1991, and 1992 ranged from 6.3 to 7.6. The pH of the trenches indicates that some adsorption to surfaces may occur over time, thereby adversely affecting the recharge capacity of the trenches. Comparison of mean pH values for Trenches 1-10 in 1990 and 1991 indicates that the mean pH had dropped by one full unit. In 1992, the pH values for Trenches 1-10 were the same as the pH values for Trenches 1-10 in 1990. The pH of the water in Trenches 11-15 measured in 1991 and 1992 was similar to the pH values measured in Trenches 1-10 during the 1990 sampling.

61. The conductivity in 1990 ranged from 1,400 μmhos in Trench 6 to 2,400 μmhos in Trench 9. The conductivity for Trenches 1-15 in 1991 ranged from 1,200 μmhos in Trench 1 to 2,300 μmhos in Trench 9. In 1992, the conductivity was highest in Trench 3 at 2,400 μmhos to a low of 1,800 μmhos in Trench 12. The conductivity of the water samples from Trenches 1-10 in 1990 was nearly identical to those values measured in water samples from Trenches 11-15 in 1991 and 1992 (Table 15). However, conductivity values for

Trenches 1-10 increased in 1991 and 1992 as compared with the 1990 values. Significant difference did not occur in salinity between the salinity values measured for Trenches 1-10 in 1990 and those determined for either Trenches 1-10 or Trenches 1-15 in 1991 and 1992 (Table 15). Both the conductivity and salinity values are all within the range of values found in groundwater and should not adversely affect the microbial populations.

62. The physical and chemical conditions observed in Trenches 1-10 have changed from 1990 to 1992. However, the data cannot be used to definitely determine whether this is a result of changing flow rates or aging and changing environmental conditions in the trenches. The change may be attributable to increased microbial activity and buildup of oxidized sludge within the trenches. In 1991 and 1992, the new trenches (11-15) had similar physical/chemical characteristics as did Trenches 1-10 after they were operational for approximately 1 year (1990). For example, the decline in pH in Trenches 1-10 observed in 1991 may possibly result from organic acid production by fermenters under reduced oxygen tension. However, the number of fermenters observed in these trenches in 1991 and 1992 declined from the 1990 values. In summary, the physical and chemical data collected from 1990 to 1992 indicate that environmental conditions within the trenches were generally conducive to microbial growth.

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63. Table 16 presents the number of fermenters enumerated in the trenches over 3 years of sampling. The 1990 sampling had the highest number of fermenters enumerated. The 1990 enumeration effort measured a net increase in fermenter numbers compared with the 1989 sampling. However, the population of fermenters enumerated in 1991 declined by one to two orders of magnitude as compared with 1990 values, and the 1992 population of fermenters declined one or two orders of magnitude from 1991. During the 1991 sampling effort, the DO levels of Trenches 1-10 were predominantly anerobic or nearly so. Therefore, in 1992 the enumeration of facultative anaerobes was conducted under conditions designed to maintain their anaerobic integrity. Samples collected in the field for facultative anaerobes were done so in nitrogen-purged collection flasks. A nitrogen-purged glove box was used for innoculation of media. Innoculated media were incubated under a nitrogen atmosphere. There were no positive results for sulfate reducers in samples from previous years.

64. Table 17 presents the number of aerotolerant heterotrophs enumerated in water samples collected from the trenches during 1989, 1990, 1991, and 1992. The highest number of aerotolerant heterotrophs were found in 1989 and 1991 over the 4-year sampling period. However, the levels varied only slightly during the 4 years of sampling. This uniformity suggests little change in the available substrate and environmental conditions required to support the growth of these organisms.

65. Facultative anaerobes were not enumerated in 1990. The 1989, 1991, and 1992 facultative enumeration data are presented in Table 18. A decrease of one to three orders of magnitude of these microorganisms enumerated in Trenches 4, 5, and 7 occurred from 1989 to 1991. In 1992, there was a decrease of one to four orders of magnitude from the previous year, 1991.

66. Table 18 presents the levels of fungi enumerated from water samples collected from the 1989, 1990, 1991, and 1992 sampling efforts. As with the bacteria enumeration data, the levels of fungi enumerated from Trenches 1-10 were highest in 1990. Fungi populations enumerated in the water samples from Trenches 11-15 in 1991 were comparable with the 1990 levels of Trenches 1-10. The fungi levels enumerated in Trenches 1-10 decreased from 1990 to 1992. The predominant fungus identified in 1989 and 1990 was *Aspergillus niger*. Since fungi such as *Aspergillus* do well under moist, but not flooded conditions, the increased numbers in 1990 suggest that water levels in the piezometer tubes remained at low levels for several days at a time so that fungus can grow.

67. Very few iron bacteria (Table 21), were found in 1990. Trenches 3, 5, and 8 were the only trenches in which iron bacteria were found. Because of the low numbers in 1990, iron bacteria enumeration was not performed in 1991 or 1992.

68. Collection of water samples from Trench 1 in 1989 was unsuccessful because of lack of water within the trench. A significant quantity of orange-red sludge was observed on the bottom of Trench 1, while none of the other trenches sampled in 1989 had any observable amounts of sludge present. Subsequent chemical analysis of the sludge verified the sludge as iron oxide. The 1990, 1991, and 1992 sampling indicated iron oxides present in all the trenches. Based on field observations, the amount of iron oxide appeared to have increased from 1989 to 1991. However, the amount of sludge in 1992 was less than observed in 1991 or 1990. During all four sampling efforts, iron oxide appeared on the bottom of all water samples left open to the atmosphere. The development of iron oxide at the bottom of sample bottles indicates that

iron is generally reduced upon entering the trench. The buildup of oxidized iron in the trenches is probably due to the partial oxidation of the reduced iron once the water enters the trenches (reduced iron in solution is very labile in the presence of oxygen). However, the presence of the iron oxide in the sample bottles indicates that much of the reduced iron is probably passed through the trench sides and bottom without precipitation as an oxide. The air may be introduced in the treated reinjection water through the numerous pipes and piezometer tubes penetrating and/or through the ground itself. The large excursions in water levels in the piezometer tubes themselves create the opportunity for air to move in and out of the trenches. Microorganisms may also impact the fate of iron within the trench environment by reduction of the iron as an electron acceptor for the facultative and fermenters during periods of low oxygen tension. Once aerobic conditions return, iron oxidizing autotrophic populations may then oxidize as an energy source.

69. Nutrients are required for microbial metabolism and reproduction. The specific nutritional requirements for different organisms vary greatly (Atlas 1988). Nitrogen and phosphorus along with hydrogen, carbon, oxygen, and sulfur constitute 95 percent of the cellular dry weight of organisms. Calcium, iron, manganese, and a few other elements are also required in trace amounts. Nutrient data collected (Table 20) indicate that several of these nutrients are present in substantial quantities in several of the trenches.

70. Nitrogen and phosphate data of 1990 and 1991 are presented in Table 22. Mean levels for various forms of nitrogen and phosphorus present in Trenches 1-10 from 1990 to 1992 and Trenches 11-15 in 1991 and 1992 are presented in Table 23. The low total kjeldahl nitrogen values indicate that the bulk of the nitrogen present is in inorganic form, mostly nitrate-nitrogen. The low values for ammonia-nitrogen and high values for nitrate-nitrogen suggest that some level of oxygen is present. Determining from the data whether or not nitrification (i.e., conversion of ammonia to nitrate by microorganisms) may be actively occurring within the trenches is not possible. Significant changes did not occur in the various forms of nitrogen present in Trenches 1-10 from 1990 to 1992. A considerably larger amount of total phosphorus than orthophosphate phosphorus was present in Trenches 1-10 in 1990, but not in 1991 or 1992. Calcium, iron, and manganese data are presented in Table 24. The calcium levels remained constant during the 3 years of sampling. The amount of total iron and manganese present in water samples collected from Trenches 1-10 increased by approximately two orders of magnitude

from 1990 to 1991 and returned to the 1990 levels in 1992. The concentrations of nutrients varied from year to year; however, the levels found are not limiting to the various types of microorganisms enumerated. Fluctuations in nutrient concentrations with time are common in microbial ecosystems. The concentration, rate of formation, or absence of a nutrient may determine the composition of a community (Alexander 1971). The dominance of different microbial types from year to year is indicative of the changing environment.

71. The design of the piezometer tubes in the five new trenches (11-15) differs from the piezometer tubes in the original ten trenches (1-10). In the original 10 trenches, the piezometer tubes are bottom screened. In Trenches 11-15, the piezometer tubes are fully screened. Because of this new design, microbial samples from Trench 12 were collected at three locations: the top, middle, and the bottom of the piezometer tube. This was done to evaluate if microbial populations varied with depth. Table 25 presents these data. These data indicate that there is no correlation between piezometer depth and microbial population.

72. The microbial activity of the piezometer tubes and the trenches can be formulated based on sample collection and analysis of the past 4 years. When the water level is down, the piezometer tubes are moist, but not dry, creating favorable conditions for the growth of fungi and aerobes and the oxidation of reduced iron. When the water levels move up, the opportunity for fresh oxygen to enter the system decreases; low dissolved oxygen levels or anaerobic conditions can gradually develop in the system. Under these conditions, first aerobes, then fermenters and facultative anaerobes grow. Even though conditions are adequate to support microbial growth, presently consistent increase does not occur in microorganisms that may lead to microbial fouling of the trenches.

73. Physical and chemical data collected to date indicate that the trenches may be going through a dynamic period of aging. Physical and chemical data from Trenches 11-15 are similar to those values measured in Trenches 1-10 when they were approximately 1 year old. The older trenches show an increase in iron, magnesium, and conductivity and a reduction in pH. The impact of this aging process on trench performance is not known, nor is it known if it is biotic or abiotic in nature.

74. An increase in the observed amount of iron oxide present on the trench bottoms in 1991 was noted; however, the amount decreased in 1992. Whether or not this apparent increase in iron oxides is occurring within the

whole trench or just in the general proximity of the piezometer tubes is not known. If it is a localized phenomenon, then it should not have an adverse effect on trench performance. However, if the buildup is trench wide, then it may have a serious impact on trench performance by reducing the hydraulic conductivity of the trench/aquifer interface. Reduction in hydraulic conductivity will result in a net reduction in recharge capacity.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

General Conclusions

75. An overall assessment of the NBS solids removal and recharge system can be concluded as follows:

- a. The average suspended solids concentration of plant effluent using the old design was not as high as expected.
- b. The changes in system design implemented as an IRA should improve the solids retention capacity of the NBS.
- c. Reduction in recharge well capacity is probably due to a combination of both carbon fines and microbial fouling.
- d. The data collected to date is inconclusive in terms of the potential for reductions in recharge trench performance to occur with time.

Specific Conclusions

76. The following specific conclusions can be made based on the results of the various efforts at the NBS to date:

Conclusions on pre-IRA system configuration

- a. High solids loading at the head of the treatment plant adversely affected plant effluent suspended solids concentrations.
- b. Carbon fines may be migrating through the spiral-wound cartridge filters under high solids loading conditions.
- c. On average, carbon fines concentrations for adsorber influents and effluents were of similar magnitudes, although two of the adsorbers released more solids than they received. Inefficient defining of the fresh carbon prior to transfer may be responsible for the release of carbon fines from the top of the adsorbers.
- d. All sumps sampled contained carbon fines and require cleaning.
- e. Although no carbon fines were detected in well water samples collected during this study, carbon fines were found in the recharge well in-line Y-strainers. Relatively large carbon fine particles are reaching the wells, indicating postfilters are failing periodically. Therefore, some carbon fines are reaching the wells on an intermittent basis.
- f. Particle size analysis indicates that conversion from a 10-μm filter to a 5-μm filter size for the postfilters should improve the overall solids removal efficiency at the NBS by approximately 16 percent.

g. The NBS effluent has a neutral pH (7.7) and may be considered in a borderline oxidized state.

h. Fungi and heterotrophic aerotolerants were not enumerated at significant levels in water samples collected from the recharge wells sampled.

i. Facultative and fermenters were enumerated at very high populations in the recharge well water.

Conclusions on post-IRA system configuration

a. Physical/chemical data indicate that the trenches may be undergoing an aging process.

b. To date, microbial populations indicate no observable trends, thereby indicating that the potential for reduction in recharge trench capacity because of excessive microbial growth is small.

c. There are sufficient quantities of both micronutrients and macronutrients to support microbial activity.

d. Iron and manganese oxides are fluctuating within the piezometer tubes. The extent of cation oxide sludge buildup is not known.

e. The changing water levels in the piezometer tubes create an environment where aerobes, fermenters, and facultative anaerobes can coexist.

Recommendations

77. The following recommendations for improving post-IRA system performance include:

a. A comprehensive evaluation of both influent and effluent filter performance should be considered to determine if maximum solids removal efficiency has been obtained with IRA improvements.

b. Installation of a multichannel turbidity unit may significantly improve defining efficiently. This installation will ensure that varying fresh carbon quality does not reduce defining efficiency with increased fines content.

c. If degradation in recharge well persists, then a well cleaning procedure capable of destroying microbiological growth and removing carbon fines should be investigated for restoring well recharge capacities to near design capabilities.

d. A method for assessing changes in trench recharge capacity should be developed. A quarterly assessment of trench recharge capacity should be performed to determine if reductions in trench recharge capacity is occurring with time.

e. Evaluation of the microbiological, physical, and chemical characteristics of the recharge trenches should be made every 2 years to determine if reduced capacity is occurring.

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Table 1

North Boundary Treatment System

Mass Flux Sampling Points

Sample Location	Number Collected	Frequency
Influent to prefilter A	10	9/13 - 9/23
Influent to prefilter B	10	9/13 - 9/23
Influent to prefilter C	10	9/13 - 9/23
Influent to adsorber A	5	9/13 - 9/16
Influent to adsorber B	5	9/13 - 9/16
Influent to adsorber C	5	9/13 - 9/16
Prefilter A effluent	4	9/14 - 9/16
Prefilter B effluent	3	9/14 - 9/16
Prefilter C effluent	3	9/14 - 9/16
Adsorber A effluent	9	9/13 - 9/23
Adsorber B effluent	9	9/13 - 9/23
Adsorber C effluent	9	9/13 - 9/23
Floor drain sump input into sump A	1	9/13
Carbon wash rinse water	5	9/13 and 9/16
Bottom effluent sump	2	9/15 and 9/23
Recharge well No. 8	4	9/19 - 9/22
Recharge well No. 19	9	9/13 - 9/23
Recharge well No. 21	5	9/13 - 9/23
Recharge well No. 24	6	9/16 and 9/19 - 9/23
Floor drain input to flood drain	1	9/13 sump
Plant effluent	13	9/13 - 9/23

Table 2

Mass Flux around Prefilter A

Date	Time hr	Cumulative Time hr	(SS) Influent mg/ℓ	(SS) Effluent mg/ℓ
13 Sep	1000	2.00	329.93	
14 Sep	1450	30.83	0.74	15.97
15 Sep	1500	55.00	5.01	1.93
16 Sep*	0930	73.50	1.30	2.90
16 Sep*	1320	77.33	0.66	0.57
			(0.98)*	(1.74)*
19 Sep	1630	152.50	0.00	
21 Sep	1500	199.00	6.40	
22 sep	1520	223.33	2.32	
23 Sep	1425	246.42	1.62	

Average influent concentration	38.67
Standard deviation influent	102.99
Average effluent concentration	5.34
Standard deviation effluent	6.19

* Indicates the average of multiple readings.

Table 3

Mass Flux around Adsorber A

Date	Time hr	Cumulative Time hr	(SS) Influent mg/ℓ	(SS) Effluent mg/ℓ
13 Sep	1000	2.00	5.16	3.77
13 Sep	1410	6.17	0.00	0.94
				(2.36)*
14 Sep	1450	30.83	0.00	0.00
15 Sep	0900	49.00	0.00	1.42
15 Sep	1500	55.00	1.41	0.00
				(0.71)*
16 Sep	1320	77.33	1.44	0.00
19 Sep	0905	145.00	--	1.22
19 Sep	1615	152.25	--	0.84
			--	(1.03)*
20 Sep	1510	175.17	--	0.90
21 sep	0830	192.50	--	0.64
22 Sep	0855	219.92	--	0.80
22 Sep	1525	223.40	--	0.73
			--	(0.77)*
23 Sep	0900	241.00	--	0.66
23 Sep	1455	246.92	--	0.52
			--	(0.59)*

Average effluent concentration	0.89
Standard deviation effluent	0.90
Average influent concentration	1.34
Standard deviation influent	1.83

* Indicates the average of multiple readings.

Table 4

Mass Flux around Prefilter B

Date	Time hr	Cumulative Time hr	(SS) Influent mg/ℓ	(SS) Effluent mg/ℓ
13 Sep	1000	2.00	431.13	
14 Sep	1450	30.83	0.00	29.50
15 Sep	1500	55.00	0.54	0.78
16 Sep	1320	77.33	0.00	0.83
19 Sep	1630	152.50	0.00	
21 Sep	1500	199.00	1.73	
22 Sep	1520	223.33	0.00	
23 Sep	1425	246.42	0.00	

Average influent concentration	54.18
Standard deviation influent	142.48
Average effluent concentration	10.37
Standard deviation effluent	13.53

Table 5

Mass Flux around Adsorber B

Date	Time hr	Cumulative Time hr	(SS) Influent mg/ℓ	(SS) Effluent mg/ℓ
13 Sep	1000	2.00	2.62	5.70
14 Sep	1450	30.83	0.73	1.42
15 Sep	1500	55.00	1.62	1.29
16 Sep	1320	77.33	0.00	0.60
19 Sep	1615	152.25	--	1.00
20 Sep	1510	175.17	--	0.51
21 Sep	0830	192.50	--	0.00
22 Sep	0855	216.92	--	0.00
23 Sep	0900	241.00	--	1.42

Average effluent concentration	1.33
Standard deviation effluent	1.63
Average influent concentration	1.24
Standard deviation influent	0.98

Table 6

Mass Flux around Prefilter C

Date	Time hr	Cumulative Time hr	(SS) Influent mg/ℓ	(SS) Effluent mg/ℓ
13 Sep	1000	2.00	189.03	--
14 Sep	1450	30.83	4.19	2.08
15 Sep	1500	55.00	0.72	1.18
16 Sep	1320	77.33	0.69	0.92
19 Sep	1630	152.50	1.26	--
21 Sep	1500	199.00	1.36	--
22 Sep	1520	223.33	10.29	--
23 Sep	1425	246.42	0.00	--

Average influent concentration	25.94
Standard deviation influent	61.72
Average effluent concentration	1.39
Standard deviation effluent	0.50

Table 7

Mass Flux around Adsorber C

Date	Time hr	Cumulative Time hr	(SS) Influent mg/ℓ	(SS) Effluent mg/ℓ
13 Sep	1000	2.00	2.66	0.72
14 Sep	1450	30.83	0.53	0.00
15 Sep	1500	55.00	0.00	0.00
16 Sep	1320	77.33	--	0.00
19 Sep	0905	145.08	--	0.52
19 Sep	1615	152.25	--	1.09
			--	(0.81)*
20 Sep	1510	175.17	--	0.00
21 Sep	0830	192.50	--	1.55
22 Sep	0855	216.92	--	0.00
22 Sep	1525	223.42	--	1.88
				(0.94)*
23 Sep	0900	241.00	--	0.00
23 Sep	1500	247.00	--	0.00
				(0.00)*

Average effluent concentration	0.48
Standard deviation influent	0.65
Average influent concentration	1.06
Standard deviation effluent	1.15

* Indicates the average of multiple readings.

Table 8

Mass Flux Postbag Filter

Date	Time hr	Cumulative Time hr	(SS) Effluent mg/ℓ
13 Sep	1000	2.00	2.39
14 Sep	1450	30.83	0.00
15 Sep*	0920	49.33	0.69
15 Sep*	1500	55.00	0.77
			(0.73)*
16 Sep	1320	77.33	0.00
20 Sep	1505	175.08	0.00
22 Sep	1510	223.17	0.00
23 Sep	1420	246.33	0.00

Average effluent concentration	0.48
Standard deviation	0.78

* Indicates the average of multiple readings.

Table 9

Mass Flux Plant Effluent

Date	Time hr	Cumulative Time hr	(SS) Effluent mg/ℓ
13 Sep	1000	2.00	1.56
14 Sep	1450	30.83	0.00
15 Sep	0920	49.33	0.00
15 Sep	1500	55.00	0.00
			(0.00)*
16 Sep	0900	73.00	0.96
16 Sep	1320	77.33	0.87
16 Sep	1618	80.30	0.00
			(0.61)*
21 Sep	0840	192.67	1.32
21 Sep	1518	199.30	1.08
			(1.20)*
22 Sep	0850	216.83	0.00
22 Sep	1515	223.25	0.00
			(0.00)*
			0.00
23 Sep	0905	241.08	0.00
23 Sep	1455	246.92	0.00
			(0.00)*

Average effluent concentration	0.45
Standard deviation	0.58

* Indicates the average of multiple readings.

Table 10

Average Influent and Effluent Concentrations, Standard Deviation and Removal Efficiencies for NBS Process Equipment

	Average Influent Conc.	Influent Std. Dev.	Average Effluent Conc.	Effluent Std. Dev.	Removal Efficiency %
Prefilter A	38.7	103.0	5.3	6.2	86.3
Adsorber A	0.9	0.9	1.3	1.8	-44.4
Prefilter B	54.2	142.5	10.4	13.5	80.8
Adsorber B	1.3	1.6	1.2	1.0	7.7
Prefilter C	25.9	61.7	1.4	0.5	94.6
Adsorber C	0.5	0.7	1.1	1.1	-120.0
Postbag	1.2*	--	0.5	0.8	58.3
Plant Effluent	--	--	0.5	0.6	--

* Flow weighted average based on flows of 50, 90, and 90 gpm for adsorbers A, B, and C, respectively.

Table 11

Particle Sizes on a Mass (Volume) and Frequency (Population) Basis for Selected Locations

Sampling Location	Sample No.	Mass Basis Statistics μm				Frequency Basis Statistics μm			
		Dg*	Dm*	Da*	Dd*	Dg	Dm	Da	Dd
Carbon wash Initial rinse	RMA-5	15.8	27.6	44.9	88.1	0.84	0.82	0.97	0.79
Carbon change Floor drain	RMA-4	54.1	71.6	78.6	123.4	2.40	1.94	3.24	1.29
Input to A-Sump from carbon wash sump	RMA-6	6.8	6.6	8.0	5.3	2.67	2.54	3.21	1.95
Bottom of E-Sump (9-15-88)	RMA-2	61.5	66.6	74.6	87.7	7.92	6.60	10.80	3.50
Bottom of E-Sump (9-23-88)	RMA-3	57.6	66.4	78.0	98.6	1.80	1.43	2.42	1.17
Recharge Well 21 Screen	RMA-1	47.4	51.8	64.7	56.7	5.34	4.43	11.48	3.59

* Dg = the geometric mean size. Dm = the median size. Da = the arithmetic average size. Dd = the mode size.

Table 12

Recharge Trench Physical Data for 1990

Trench Number	Water Depth*	Temp °C	DO mg/ℓ	pH	Cond. µmhos	Salinity ppt
1	5' 4"	12	1.7	7.4	1625	0.5
2	4' 5"	11	4.9	7.4	1725	0.8
3	4' 0"	12	2.4	7.6	1850	0.9
4	6' 0"	12	2.1	7.5	1975	0.5
5	10' 2"	12	2.7	7.2	1550	0.5
6	10' 2"	12	2.7	7.4	1400	0.5
7	5' 0"	12	2.9	6.7	1650	0.5
8	4' 1"	13	2.9	6.9	1900	0.5
9	4' 7"	14	2.4	6.3	2400	1.0
10	7' 0"	13	2.2	6.4	2000	1.0

* Measured from top of the polyvinyl chloride (PVC) tubes.

Table 13

Recharge Trench Physical Data for 1991

Trench Number	Water Depth*	Temp °C	DO mg/ℓ	pH	Cond. μmhos	Salinity ppt
1	2′ 0"	23	0.8	6.8	1200	0.5
2	1′ 6"	18	0.7	6.5	1900	1.2
3	6′ 4"	18	0.8	7.1	2100	1.0
4	10′ 7"	19	0.5	7.2	2150	1.5
5	15′ 9"	19	0.3	7.0	2100	1.0
6	7′ 5"	17	0.6	6.5	2100	1.0
7	5′ 1"	17	0.8	6.6	2100	1.5
8	3′ 2"	18	0.2	6.5	2200	1.5
9	3′ 5"	18	0.4	6.7	2300	1.5
10	8′ 8"	16	0.6	7.0	2100	1.5
11	8′ 9"	14	3.7	7.5	1500	1.0
12	9′ 7"	16	3.6	7.3	1800	1.0
13	10′ 10"	14	2.7	7.5	1550	1.0
14	9′ 11"	13	2.9	7.6	1950	1.5
15	1′ 0"	13	2.9	7.6	1950	1.5

* Measured from top of the PVC tubes.

Table 14

Recharge Trench Physical Data for 1992

Trench Number	Water Depth*	Temp °C	DO mg/ℓ	pH	Cond. μmhos	Salinity ppt
1	0.5′ 0″	ND**	0.6	ND	ND	ND
2	0.5′ 0″	ND	0.5	ND	ND	ND
3	2′ 5″	22	0.7	7.1	2400	1.5
4	8′ 0″	21	1.0	7.2	2200	1.5
5	12′ 5″	21	1.5	6.9	2000	1.2
6	11′ 0″	16	1.5	7.0	2000	1.2
7	6′ 2″	16	0.3	7.0	2000	1.2
8	5′ 6″	17	0.5	7.0	1995	1.1
9	4′ 8″	14	0.5	7.0	1900	0.9
10	7′ 3″	14	0.3	6.9	1900	1.0
11	5′ 9″	14	3.8	6.9	1900	1.0
12	7′ 9″	14	2.7	6.9	1800	1.0
13	3′ 4″	15	3.5	7.0	2000	2.0
14	13′ 1″	16	3.0	6.9	2100	2.0
15	10′ 7″	16	5.5	6.9	2000	1.2

* Measured from top of the PVC tubes.
** ND = Not determined because of insufficient water in piezometer tube.

Table 15

Comparison of 1990, 1991, and 1992, Data for Temperature, Dissolved Oxygen, Conductivity, and Salinity

Constituent	1990 Value* Trenches 1-10	1991 Value* Trenches 1-15	1991 Value* Trenches 1-10	1991 Value* Trenches 11-15	1992 Value* Trenches 1-15
Temperature °C	12 ± 0.3	17 ± 0.7	18 ± 0.6	14 ± 0.5	17 ± 0.79
Dissolved Oxygen mg/ℓ	2.5 ± 0.37	1.4 ± 0.34	0.6 ± 0.10	3.2 ± 0.20	1.7 ± 0.4
pH	7.1 ± 0.15	6.4 ± 0.48	6.1 ± 0.66	7.5 ± 0.06	7.0 ± 0.03
Conductivity µmhos	1808 ± 90	1667 ± 170	2025 ± 97	1750 ± 96	2046 ± 41
Salinity, ppt	1.9 ± 0.90	1.2 ± 0.08	1.3 ± 0.13	1.2 ± 0.12	1.32 ± 0.09

Constituent	1992 Value* Trenches 1-10	1992 Value* Trenches 11-15
Temperature °C	18 ± 0.91	16 ± 1.23
Dissolved Oxygen mg/ℓ	0.74 ± 0.5	3.7 ± 0.71
pH	7.04 ± 0.03	6.96 ± 0.04
Conductivity µmhos	2090 ± 47	1956 ± 65.0
Salinity, ppt	1.26 ± 0.11	1.09 ± 0.16

* Values are mean ± standard error.

Table 16

Recharge Trench Fermenter Enumeration Results

Trench Number	Number of Bacteria per Milliliter of Groundwater 1989	1990	1991	1992
1	NM*	2.2×10^4	9.0×10	NM
2	NM	1.3×10^4	1.3×10^2	1.8×10
3	NM	1.8×10^4	1.7×10^2	6.0×10^{-1}
4	1.3×10^2	1.8×10^5	2.4×10^3	3.5×10
5	1.3×10^2	9.4×10^4	3.5×10^3	2.4×10
6	NM	2.3×10^4	1.7×10^2	2.4×10
7	2.2×10^3	2.3×10^4	1.7×10^3	9.2×10
8	NM	4.3×10^4	NM	1.4×10^0
9	NM	2.3×10^4	2.7×10^2	1.3×10^0
10	NM	2.3×10^4	1.1×10^2	9.2×10
11	NM	NM	2.4×10^3	1.7×10^0
12	NM	NM	4.9×10^3	6.0×10^{-1}
13	NM	NM	5.4×10^3	4.0×10^{-1}
14	NM	NM	2.3×10^4	6.0×10^{-1}
15	NM	NM	9.2×10^3	3.1×10^0

* NM = not measured.

Table 17

Recharge Trench Aerotolerant Heterotroph Enumeration Results

Trench Number	Number of Bacteria per Milliliter of Groundwater			
	1989	1990	1991	1992
1	NM*	4.9×10^2	1.7×10^3	NM
2	NM	3.5×10^3	2.4×10^3	3.5×10^2
3	NM	3.1×10^4	4.6×10^3	3.3×10
4	1.3×10^3	1.8×10^3	5.4×10^3	1.7×10^2
5	7.9×10^3	2.3×10^2	1.7×10^2	2.4×10^2
6	NM	9.0×10^1	2.3×10^2	7.9×10^4
7	2.3×10^4	2.2×10^4	2.4×10^3	2.3×10^2
8	NM	7.9×10^3	5.4×10^3	7.9×10
9	NM	2.3×10^4	4.9×10^2	2.3×10^2
10	NM	2.3×10^4	5.4×10^3	1.7×10^2
11	NM	NM	1.6×10^4	3.5×10
12	NM	NM	9.2×10^3	1.8×10^4
13	NM	NM	2.3×10^2	2.8×10^2
14	NM	NM	2.4×10^4	1.4×10^2
15	NM	NM	NM	3.5×10^3

* NM = not measured.

Table 18

Recharge Trench Facultative Anaerobe Enumeration Results

Trench Number	Number of Bacteria per Milliliter of Groundwater		
	1989	1991	1992
1	NM*	2.4×10^3	NM
2	NM	2.4×10^3	2.3×10^2
3	NM	2.4×10^3	2.2×10
4	5.4×10^4	3.5×10^3	2.2×10^3
5	2.3×10^4	7.0×10^3	9.2×10
6	NM	2.0×10	2.3×10^2
7	1.3×10^6	1.3×10^3	1.6×10^2
8	NM	2.4×10^3	3.5×10
9	NM	5.4×10^3	3.5×10
10	NM	1.4×10^3	2.2×10^2
11	NM	3.5×10^3	5.4×10
12	NM	1.6×10^4	4.6×10
13	NM	5.4×10^3	3.3×10^2
14	NM	3.5×10^4	3.5×10
15	NM	3.5×10^3	7.9×10

* NM = not measured.

Table 19

1992 Anaerobically Incubated Facultative Anaerobes and Sulfate Reducers

	Number of Microorganisms per Milliliter of Groundwater	
Trench Number	Facultative Anaerobes	Sulfate Reducers
1	NM*	NM
2	2.7×10^3	0
3	2.2×10	0
4	2.2×10^3	0
5	7.9×10	0
6	2.3×10	5
7	3.3×10^3	0
8	6.3×10	0
9	6.3×10	0
10	2.2×10^3	0
11	4.9×10	0
12	4.6×10	0
13	3.5×10^2	0
14	6.3×10	0
15	7.9×10	0

* NM = not measured.

Table 20

Recharge Trench Fungi Enumeration Results

Trench Number	Number of Fungi per 100 ml* of Groundwater 1989	1990	1991	1992
1	NM**	94.0	28	NM
2	NM	129.0	2	0
3	NM	188.0	18	30
4	8.2	0.0	40	0
5	9.9	140.0	18	8
6	NM	NM	2	7
7	4.0	4.0	6	1
8	NM	106.0	36	4
9	NM	47.0	38	4
10	NM	753.0	NM	7
11	NM	NM	182	5
12	NM	NM	92	7
13	NM	NM	56	40
14	NM	NM	19	51
15	NM	NM	62	500

* Because of expected low population of fungi, 100 ml was analyzed.
** NM = not measured.

Table 21

1990 Recharge Trench Iron Bacteria

Enumeration Results

Trench Number	Number of Bacteria per 100 ml of Groundwater
1	0
2	0
3	2
4	0
5	1
6	0
7	0
8	1
9	0
10	0

Table 22

Nutrient Analysis (Milligrams per Liter) of Recharge Trenches in 1990, 1991, and 1992

Trench	Total Kjeldahl Nitrogen			Total Phosphorus			Orthophosphate			Nitrite Nitrogen			Nitrate Nitrogen			Ammonia Nitrogen		
	1990	1991	1992	1990	1991	1992	1990	1991	1992	1990	1991	1992	1990	1991	1992	1990	1991	1992
1	1.120	1.400	NM*	3.01	2.850	NM	0.348	3.680	NM	<0.01	0.014	NM	1.16	1.200	NM	<0.010	<0.010	NM
2	1.120	0.362	NM	1.91	0.153	NM	0.029	0.168	NM	<0.01	<0.005	NM	1.14	1.190	NM	0.673	<0.010	NM
3	1.040	0.661	1.21	2.05	1.230	2.230	0.132	1.610	3.028	<0.01	0.006	0.051	0.90	0.571	0.373	<0.010	<0.010	0.233
4	1.290	0.403	0.823	7.64	0.644	1.770	0.380	0.851	2.751	<0.01	<0.005	<0.010	0.73	1.240	1.11	0.022	<0.010	0.143
5	1.080	0.642	0.612	4.24	1.350	1.260	0.870	1.810	1.497	<0.01	<0.005	<0.010	0.97	1.090	1.12	0.063	<0.010	0.138
6	1.040	0.539	1.160	5.52	3.800	0.779	0.410	5.070	0.806	<0.01	0.022	<0.010	0.97	0.481	1.23	0.017	<0.010	<0.010
7	0.996	0.545	0.594	2.80	0.871	0.198	0.460	1.120	0.039	<0.01	<0.005	<0.010	1.01	1.230	1.3	0.025	<0.010	0.292
8	0.983	0.778	1.000	3.40	3.900	2.950	0.249	4.960	3.999	<0.01	0.019	<0.010	0.92	0.427	1.33	0.016	<0.010	0.115
9	1.160	0.472	0.547	10.60	4.140	0.639	0.161	4.320	0.549	<0.01	0.007	<0.010	0.99	0.618	1.21	<0.010	<0.010	0.115
10	0.886	0.575	0.452	2.53	1.580	0.451	0.161	1.870	0.308	<0.01	0.015	<0.010	0.10	0.674	1.16	0.692	<0.010	0.101
11	NIE	0.641	0.350	NIE	0.422	0.398	NIE	0.352	0.285	NIE	<0.005	<0.010	NIE	0.205	1.44	NIE	<0.010	0.055
12	NIE	0.574	0.295	NIE	0.303	0.308	NIE	0.274	0.256	NIE	<0.005	<0.010	NIE	1.630	1.41	NIE	<0.010	0.049
13	NIE	0.707	0.490	NIE	0.375	0.383	NIE	0.251	0.294	NIE	<0.005	<0.010	NIE	0.938	1.44	NIE	<0.010	0.052
14	NIE	<0.050	0.508	NIE	0.549	0.321	NIE	0.377	0.218	NIE	<0.005	<0.010	NIE	0.945	1.31	NIE	0.169	0.092
15	NIE	0.602	0.606	NIE	0.112	0.341	NIE	0.062	0.258	NIE	0.006	<0.010	NIE	<0.005	1.44	NIE	0.089	0.079

* NM = not measured; NIE = not in existence.

Table 23

Mean Levels of Nutrients and Metal Present in Recharge

Trenches during 1990, 1991, and 1992

Parameter	1990 Values* for Trenches 1-10	1991 Values* for Trenches 1-10	1991 Values* for Trenches 11-15	1992 Values* for Trenches 1-10	1992 Values* for Trenches 11-15
Total Kjeldahl Nitrogen	1.072 ± 0.035	0.638 ± 0.093	0.505 ± 0.128	0.800 ± 0.097	0.450 ± 0.050
Nitrate-Nitrogen	0.889 ± 0.096	0.872 ± 0.109	0.744 ± 0.292	1.058 ± 0.144	1.408 ± 0.022
Ammonia-Nitrogen	0.151 ± 0.089	0	0.052 ± 0.034	0.143 ± 0.029	0.065 ± 0.008
Total Phosphorus	4.37 ± 0.888	2.05 ± 0.470	0.352 ± 0.072	1.285 ± 0.317	0.350 ± 0.016
Orthophosphate-Phosphorus	0.320 ± 0.075	2.55 ± 0.568	0.262 ± 0.055	1.622 ± 0.483	0.262 ± 0.012
Calcium	154 ± 4.51	136 ± 28.6	159 ± 17.7	161.750 ± 2.370	161.385 ± 1.641
Iron	79.4 ± 30.3	2303 ± 2046	41.4 ± 23.3	94.150 ± 25.897	60.091 ± 19.921
Manganese	0.062 ± 0.019	1.03 ± 0.615	1.64 ± 0.484	0.181 ± 0.024	0.245 ± 0.069

* Values given are milligrams per liter ± standard error.

Table 24

Calcium, Iron, and Manganese concentrations, mg/ℓ

Trench Number	Calcium			Iron			Manganese		
	1990	1991	1992	1990	1991	1992	1990	1991	1992
1	146	186.0	NM*	5.6	329.0	NM	0.021	0.939	NM
2	151	131.0	NM	54.1	330.0	NM	0.081	0.498	NM
3	150	157.0	162	57.1	321.0	139.0	0.053	0.133	0.258
4	184	120.0	169	139.0	80.3	86.3	0.124	0.260	0.123
5	170	74.1	167	11.8	4.9	76.8	0.024	0.067	0.199
6	138	37.7	152	45.9	27.3	63.8	0.013	0.167	0.219
7	147	166.0	155	63.2	201.0	23.5	0.078	0.436	0.139
8	164	136.0	172	80.2	1000.0	268.0	0.090	1.070	0.293
9	146	338.0	161	328.0	20700.0	56.0	0.117	6.480	0.101
10	145	13.3	156	8.64	39.8	39.8	0.020	0.262	0.113
11	NIE	130.0	164	NIE	5.06	9.43	NIE	0.521	0.202
12	NIE	131.0	154	NIE	131.0	5.52	NIE	1.520	0.246
13	NIE	130.0	166	NIE	4.0	4.46	NIE	1.960	1.080
14	NIE	205.0	162	NIE	30.8	5.53	NIE	0.888	0.052
15	NIE	200.0	158	NIE	35.9	3.04	NIE	3.300	0.162

* NM = not measured; NIE = not in existence.

Table 25

Comparison of Microbial Numbers at Various Sampling Depths within the Piezometer Tube of Trench 12

Trench	Location	Fermenters	Aerotolerant Heterotroph	Facultative Anaerobe
12	Top	1.7×10^4	7.9×10^3	9.2×10^3
12	Middle	4.9×10^3	9.2×10^3	1.6×10^4
12	Bottom	4.9×10^4	1.2×10^2	2.8×10^4

APPENDIX A: UNREDUCED PARTICLE SIZE DETERMINATION DATA

Basic Electrozone Technology

and

Explanation of Report

The electric sensing zone analytical technique has developed rapidly over the past 20 years. In this technique, particles suspended in a conductive fluid flow serially through an orifice under a differential pressure. Electrodes are immersed on each side of the orifice as shown in Figure A1. As each particle passes through the aperture, it replaces its own volume of electrolyte within the aperture, momentarily changing the resistance value between the electrodes. This change produces a voltage pulse of short duration having a magnitude proportional to particle volume. The resulting series of pulses is electronically amplified, scaled, and counted. Raw data processing is performed by a PDP-1103 minicomputer in such a manner that a population histogram of 128 or 256 channels of information can be acquired. Acquired data is conditioned by applying calibration, extrapolation, volume (weight), or area conversions. Normalization of size and quantity axes to the types of scales required by the researcher is also possible.

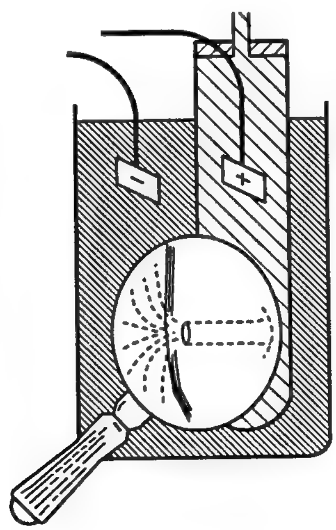

Figure A1. Basic detection mechanism

The conductive particle suspension medium is an important consideration in electrozone technology. Typically, aqueous isotonic saline (0.9 percent by weight) or a 4 percent by weight sodium pyrophosphate is used as a dispersing and particle suspension medium. For certain analyses that cannot be run in an

aqueous media, 4 percent weight/volume lithium chloride in isopropyl alcohol is effective.

Figure A2 is a cross section of the orifice shown in Figure A1. In this configuration, no particle is shown in the orifice. Since a constant current is established in the conductive liquid and through the sapphire orifice, a constant voltage potential is represented as the product of the current (I) and Resistance (R).

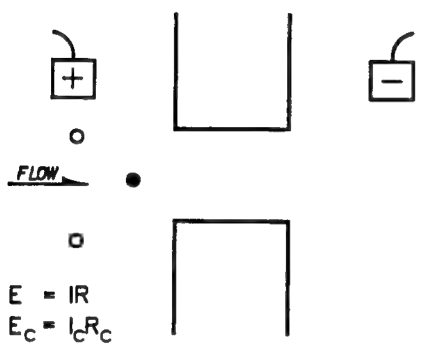

Figure A2. Cross section of orifice

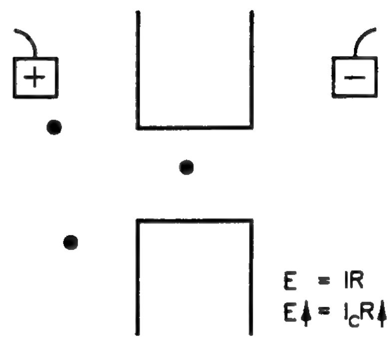

Figure A3. Cross section of orifice with particle

Figure A3 is the same condition except with a particle in the orifice or sensing zone. Since almost all particles act as insulators, the electrical resistance increases in the orifice. Under the conditions of a constant current and increased resistance, the product of these two must rise according to Ohm's Law. Since the particles traverse the orifice in about 20 μsec, a voltage pulse is produced. The magnitude of this voltage pulse is proportional to the envelope volume of the particle. That is, a small particle yields a small voltage pulse, while a large particle yields a large pulse. The particle may be irregular in shape (spheres are seldom encountered), but since the volume of that particle has been measured, the diameter of a sphere of equal volume can be assigned to the particle. This method of expressing data as the "Diameter of a Sphere of Equal Volume" is used throughout all of "Fine Particle Technology."

Now that a way of measuring discrete events rapidly and accurately exists, presenting a representative population to the detector is all that has to be done. The technologist must sample the powder in a meaningful manner

and disperse the powder so that only individual particles are monitored by the instrument. When all of these conditions have been met, the suspension is analyzed by counting and sizing no fewer than 50,000 particles of the sample. Since the accuracy and precision of the measurement is affected by the sample size, counting such a high number of particles is elected. When a present number of particles has been acquired, the computer stops the analysis. At this point, pertinent calibration information is added from the keyboard, and the frequency (population) statistics are generated. The information is then converted to a volume (mass) basis, and these statistics are reported.

These are two classic methods of fine particle size analysis:

a. Frequency distribution (Microscope counting).

b. Mass distribution (Sieves of Andreason sedimentation).

In the first method, the number of particles of a specific size are tabulated by the microscopist. He scans a microscope slide while randomly searching for a particle in the prepared slide. When one is located, it is sized using an eyepiece micrometer and counted as a frequency of occurrence. Soon a frequency distribution is established for the sample of interest. The microscopist can now calculate the relative percent of particles within a given size interval, or he can sum the data and report the percentage greater than an indicated size. Table A1 is a brief example of this procedure. Following the statistical treatment, he can plot the data to locate the geometric median diameter and then derive other statistical parameters.

Table A1

Example of Frequency Distribution Data

(μm) Particle Size Interval	d Mid Size	N Frequency of Occurrence	N≥ Cumulative Frequency	Cumulative Frequency ≥ Indicated %
1.0 - 1.4	1.2	10	100	100
1.4 - 2.0	1.7	15	90	90
2.0 - 2.8	2.4	50	75	75
2.8 - 4.0	3.2	15	25	25
4.0 - 5.6	4.8	10	10	10

What this data indicates is that 100 percent of the data measured is greater than or equal to 1.0 μm. Ninety percent is greater than 1.4 μm in diameter. This information when plotted on log-probability paper will yield a

straight line if the distribution is truly log normal (most samples are). Once that data is plotted, many statistical parameters are available to the analyst from standard formulas.

The second method of analysis is performed by a standard sieving technique. In this method, a known weight of dry sample is passed through nested precision sieves, and the weight percent retained on each sieve is calculated. Data is handled as above in Table A1 except data is expressed on a weight basis.

Since the Elzone technique determines the volume of individual particles, frequency data can be converted directly into mass or into area. Part of the job of the technologist is to determine which data format is appropriate to his application.

The Elzone data report is broken down as follows:

Page	Description
1	Frequency and Volume (Mass) Statistics
2	Plot of Differential Frequency Distribution
3	Tabulation of Channel Number, Diameter, and Count (Number of particles at that size)
4	Plot of Differential Mass Distribution
5	Tabulation of Channel Number, Diameter, and Mass (relative units at that size)

Each page will be described below:

Page 1

The top section of this page is devoted to the volume (mass) statistics. The definitions of the terms used are as follows:

Volume Mode - The diameter size in microns of a spherical particle that contains the largest total mass value. It is always the peak of a distribution curve.

Volume Median - That point in the distribution curve that splits the data into two equal areas. One half is larger and one half is smaller than the indicated size on a mass basis.

Geometric Volume Mean - The size of an average particle calculated on a log basis.

Arithmetic Volume Mean - The size of an average particle calculated on an arithmetic scale.

+/-XXX - One sigma interval of standard deviation.

(XX.XXX) - Coefficient of variation. This is the Standard Deviation divided by Mean multiplied by 100 to yield percentage.

Skewness - This term denotes symmetry. If the curve is perfectly Gaussian, geometric skewness will be 0.00. If the curve is biased towards the fines, skewness will be negative.

For Plotting on Log Probability Paper -
This data is presented at 0.77 sigma intervals across a normal curve. It expresses the percent of mass at or greater than the indicated size from a cumulative curve.

The bottom of this page is just like the top except that it expresses the statistics on a frequency (count) basis.

Remember that the frequency basis will always be smaller than mass basis, because the mass data rises as a function of the diameter cubed. It takes one million one micron diameter particles by count to equal the same mass as a single one hundred micron diameter particle.

Page 2

This page is a plot of the frequency distribution as a function of size. Each plus (+) represents a specific number of particles at a given size. The size scale is a log scale, because a Gaussian curve plotted on a arithmetic scale would be skewed towards the larger sizes. Typically, data is plotted on a log scale.

Page 3

This is the "Tabulation" page by frequency (count). The number after "Total =" represents the number of particles counted in a particular analysis. This number is usually modified by some factor so that the graph routine will be represented as a full-scale plot. The tabulation informs the client how many particles (count) he could expect to find at any indicated micron size if he had counted the number of particles indicated under "Total In Tabulation."

Page 4

This page is a plot of the mass (volume) distribution mathematically derived from the count (frequency) distribution. It reveals the distribution of mass as a function of particle size. Usually, this data is more relevant to a particular industrial process.

Page 5

The last page in the report is a tabulation of data in a mass (volume) format. It is exactly like the count tabulation except that it provides the relative mass (grams, micrograms, pounds, or tons) of material at each micron

size if one had a pile of material weighing the same as that figure displayed under "Total =."

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD
PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Thu Feb 28 1989

Time: 1:01:00 p.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-5

Job No: ID-14966

Technician: L.W

Special Comments

geometric mean size = 15.79
standard deviation = 57.33
median size = 27.61

arithmetic mean size = 44.87
coeff.of variation = 363.2
mode size = 88.11

Total = 423535030

Coincidence Corrected: No

Extrapolated above: 1.060

VOLUME DISTRIBUTION DATA

Chnl	Size	Volume	% >	Chnl	Size	Volume	% >	Chnl	Size	Volume	% >	Chnl	Size	Volume	% >
1	0.298	15821	100.00	33	1.619	5411643	87.19	65	8.791	1164338	60.44	97	47.75	6072993	38.38
2	0.314	21822	99.99	34	1.706	5506658	85.91	66	9.269	1235325	60.15	98	50.34	6207510	36.93
3	0.331	29829	99.99	35	1.799	5589736	84.60	67	9.772	1294188	59.86	99	53.08	6416115	35.44
4	0.349	40406	99.98	36	1.897	5703100	83.26	68	10.30	1335574	59.55	100	55.96	6583898	33.91
5	0.368	54243	99.97	37	2.000	5665974	81.92	69	10.86	1477464	59.21	101	59.00	6709598	32.34
6	0.388	72163	99.95	38	2.108	5612183	80.59	70	11.45	1477103	58.87	102	62.20	6718553	30.76
7	0.409	95140	99.93	39	2.223	5419183	79.29	71	12.07	1558558	58.51	103	65.58	6900259	29.15
8	0.431	124306	99.91	40	2.344	5181590	78.03	72	12.73	1672970	58.13	104	69.14	7086558	27.50
9	0.455	160953	99.87	41	2.471	5156018	76.81	73	13.42	1768220	57.72	105	72.90	7126717	25.82
10	0.480	206529	99.83	42	2.605	4958740	75.62	74	14.15	1825678	57.30	106	76.86	7233109	24.12
11	0.506	262629	99.78	43	2.747	4824927	74.46	75	14.92	1893283	56.86	107	81.03	7300450	22.41
12	0.533	330965	99.71	44	2.896	4526966	73.36	76	15.73	2003765	56.40	108	85.43	7310379	20.68
13	0.562	413332	99.62	45	3.053	4449241	72.30	77	16.58	2042117	55.92	109	90.07	7325533	18.96
14	0.593	511558	99.51	46	3.219	4328051	71.26	78	17.48	2169702	55.42	110	94.96	7235531	17.24
15	0.625	627433	99.37	47	3.394	4062762	70.27	79	18.43	2261290	54.90	111	100.1	7097169	15.54
16	0.659	762638	99.21	48	3.578	3906436	69.33	80	19.43	2302687	54.36	112	105.6	6921355	13.89
17	0.695	918644	99.01	49	3.772	3768094	68.43	81	20.49	2425946	53.80	113	111.3	6777164	12.27
18	0.732	1096615	98.77	50	3.977	3683640	67.55	82	21.60	2588653	53.21	114	117.3	6551842	10.70
19	0.772	1297296	98.49	51	4.193	3270074	66.72	83	22.77	2729135	52.58	115	123.7	6184155	9.194
20	0.814	1520903	98.16	52	4.421	3023636	65.98	84	24.01	2864561	51.92	116	130.4	5885811	7.768
21	0.858	1767023	97.77	53	4.661	2855995	65.29	85	25.32	3009126	51.23	117	137.5	5436805	6.431
22	0.905	2034514	97.32	54	4.914	2637442	64.64	86	26.69	3201945	50.50	118	145.0	4887577	5.211
23	0.954	2321437	96.81	55	5.181	2497031	64.03	87	28.14	3454516	49.71	119	152.8	4323477	4.123
24	1.006	2625012	96.23	56	5.462	2227798	63.47	88	29.67	3756016	48.86	120	161.1	3981702	3.142
25	1.060	2941599	95.57	57	5.759	1911858	62.98	89	31.28	3987257	47.95	121	169.9	3448868	2.264
26	1.118	3489451	94.81	58	6.071	1673397	62.56	90	32.98	4169902	46.98	122	179.1	2915380	1.512
27	1.179	3904370	93.94	59	6.401	1502803	62.19	91	34.77	4495004	45.96	123	188.8	2125980	0.915
28	1.243	4211486	92.98	60	6.749	1323991	61.85	92	36.66	4832878	44.86	124	199.1	1376207	0.501
29	1.310	4574031	91.95	61	7.115	1271012	61.54	93	38.65	5082888	43.69	125	209.9	888252	0.233
30	1.381	4667224	90.85	62	7.502	1171705	61.26	94	40.75	5388852	42.46	126	221.3	457407	0.073
31	1.456	5105207	89.70	63	7.909	1104715	60.99	95	42.96	5657703	41.15	127	233.3	78463	0.009
32	1.535	5360723	88.47	64	8.339	1192309	60.72	96	45.29	5859559	39.79	128	246.0	0	0.000

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD
PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Thu Feb 28 1989

Time: 1:01:00 p.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-5

Job No: ID-14966

Technician: L.W

Special Comments

Low at 1 0.298 15821 High at 128 246.0 0 Top of scale is 9830400

Graph of DIAM Size vs. Differential Volume From channel 1 to 127 skip: 2

% >	Size
100.00	0.298
99.98	0.349
99.93	0.409
99.83	0.480
99.62	0.562
99.21	0.659
98.49	0.772
97.32	0.905
95.57	1.060
92.98	1.243
89.70	1.456
85.91	1.706
81.92	2.000
78.03	2.344
74.46	2.747
71.26	3.219
68.43	3.772
65.98	4.421
64.03	5.181
62.56	6.071
61.54	7.115
60.72	8.339
59.86	9.772
58.87	11.45
57.72	13.42
56.40	15.73
54.90	18.43
53.21	21.60
51.23	25.32
48.86	29.67
45.96	34.77
42.46	40.75
38.38	47.75
33.91	55.96
29.15	65.58
24.12	76.86
18.96	90.07
13.89	105.6
9.194	123.7
5.211	145.0
2.264	169.9
0.501	199.1
0.009	233.3

% > Size 0 10 20 30 40 50 60 70 80 90 100

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Time: 1:01:00 p.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-5

Job No: ID-14966

Technician: L.W

Special Comments

PERCENTILES

0.10%	Volm	above	218.3	um
1.00%	Volm	above	187.0	um
6.00%	Volm	above	139.6	um
22.00%	Volm	above	81.88	um
50.00%	Volm	above	27.60	um
78.00%	Volm	above	2.344	um
94.00%	Volm	above	1.173	um
99.00%	Volm	above	0.696	um
99.90%	Volm	above	0.437	um

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Date: Thu Feb 28 1989

Time: 1:01:00 p.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-5

Job No: ID-14966

Technician: L.W

Special Comments

geometric mean size = 0.838
standard deviation = 0.644
median size = 0.822

arithmetic mean size = 0.966
coeff.of variation = 76.83
mode size = 0.794

Total = 3967213

Coincidence Corrected: No

Extrapolated above: 1.060

FREQUENCY DISTRIBUTION DATA

Chnl	Size	Counts	% >	Chnl	Size	Counts	% >	Chnl	Size	Counts	% >	Chnl	Size	Counts	% >
1	0.298	32554	99.60	29	1.310	110790	19.46	57	5.759	545	0.068	85	25.32	10	0.002
2	0.314	38315	98.70	30	1.381	96463	16.85	58	6.071	407	0.056	86	26.69	9	0.002
3	0.331	44690	97.66	31	1.456	90036	14.50	59	6.401	312	0.047	87	28.14	8	0.002
4	0.349	51656	96.44	32	1.535	80673	12.35	60	6.749	235	0.040	88	29.67	8	0.002
5	0.368	59172	95.05	33	1.619	69492	10.45	61	7.115	192	0.035	89	31.28	7	0.001
6	0.388	67172	93.46	34	1.706	60338	8.814	62	7.502	151	0.030	90	32.98	6	0.001
7	0.409	75568	91.66	35	1.799	52263	7.393	63	7.909	122	0.027	91	34.77	6	0.001
8	0.431	84250	89.65	36	1.897	45501	6.160	64	8.339	112	0.024	92	36.66	5	0.001
9	0.455	93084	87.41	37	2.000	38573	5.099	65	8.791	93	0.021	93	38.65	5	0.001
10	0.480	101920	84.96	38	2.108	32602	4.201	66	9.269	84	0.019	94	40.75	4	0.001
11	0.506	110592	82.28	39	2.223	26862	3.451	67	9.772	76	0.017	95	42.96	4	0.001
12	0.533	118922	79.39	40	2.344	21917	2.835	68	10.30	66	0.015	96	45.29	3	0.001
13	0.562	126730	76.30	41	2.471	18609	2.324	69	10.86	63	0.014	97	47.75	3	0.000
14	0.593	133837	73.01	42	2.605	15272	1.896	70	11.45	54	0.012	98	50.34	3	0.000
15	0.625	140072	69.56	43	2.747	12680	1.543	71	12.07	48	0.011	99	53.08	2	0.000
16	0.659	145279	65.97	44	2.896	10151	1.255	72	12.73	44	0.010	100	55.96	2	0.000
17	0.695	149325	62.25	45	3.053	8513	1.020	73	13.42	40	0.009	101	59.00	2	0.000
18	0.732	152104	58.45	46	3.219	7067	0.823	74	14.15	35	0.008	102	62.20	2	0.000
19	0.772	153542	54.60	47	3.394	5660	0.662	75	14.92	31	0.007	103	65.58	1	0.000
20	0.814	153600	50.73	48	3.578	4644	0.532	76	15.73	28	0.006	104	69.14	1	0.000
21	0.858	152277	46.88	49	3.772	3822	0.426	77	16.58	24	0.006	105	72.90	1	0.000
22	0.905	149607	43.07	50	3.977	3189	0.337	78	17.48	22	0.005	106	76.86	1	0.000
23	0.954	145663	39.35	51	4.193	2415	0.266	79	18.43	20	0.004	107	81.03	1	0.000
24	1.006	140548	35.74	52	4.421	1906	0.212	80	19.43	17	0.004	108	85.43	1	0.000
25	1.060	134394	32.28	53	4.661	1536	0.168	81	20.49	15	0.004	109	90.07	1	0.000
26	1.118	136036	28.87	54	4.914	1210	0.134	82	21.60	14	0.003	110	94.96	0	0.000
27	1.179	129882	25.51	55	5.181	978	0.106	83	22.77	13	0.003				
28	1.243	119546	22.37	56	5.462	744	0.084	84	24.01	11	0.003				

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD
PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Thu Feb 28 1989

Time: 1:01:00 p.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-5

Job No: ID-14966

Technician: L.W

Special Comments

Low at 1 0.298 32554 High at 110 94.96 0 Top of scale is 153600

Graph of DIAM Size vs. Differential Counts From channel 1 to 109 skip: 2

% >	Size
99.60	0.298
96.44	0.349
91.66	0.409
84.96	0.480
76.30	0.562
65.97	0.659
54.60	0.772
43.07	0.905
32.28	1.060
22.37	1.243
14.50	1.456
8.814	1.706
5.099	2.000
2.835	2.344
1.543	2.747
0.823	3.219
0.426	3.772
0.212	4.421
0.106	5.181
0.056	6.071
0.035	7.115
0.024	8.339
0.017	9.772
0.012	11.45
0.009	13.42
0.006	15.73
0.004	18.43
0.003	21.60
0.002	25.32
0.002	29.67
0.001	34.77
0.001	40.75
0.000	47.75
0.000	55.96
0.000	65.58
0.000	76.86
0.000	90.07

Scale: 0 10 20 30 40 50 60 70 80 90 100

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD

PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Thu Feb 28 1989

Time: 1:01:00 p.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-5

Job No: ID-14966

Technician: L.W

Special Comments

PERCENTILES

0.10%	Popl	above	5.239	um
1.00%	Popl	above	3.063	um
6.00%	Popl	above	1.908	um
22.00%	Popl	above	1.248	um
50.00%	Popl	above	0.821	um
78.00%	Popl	above	0.545	um
94.00%	Popl	above	0.381	um
99.00%	Popl	above	0.309	um
99.90%	Popl	above	0.291	um

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD
PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Wed Mar 01 1989

Time: 9:59:42 a.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RHA-4

Job No: ID-14966

Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

geometric mean size = 54.13
standard deviation = 60.60
median size = 71.58

arithmetic mean size = 78.56
coeff.of variation = 111.9
mode size = 123.4

Total = 281215512

Coincidence Corrected: No

VOLUME DISTRIBUTION DATA

Chnl	Size	Volume	% >	Chnl	Size	Volume	% >	Chnl	Size	Volume	% >	Chnl	Size	Volume	% >
1	1.000	0	100.0	33	4.118	306152	98.89	65	16.95	1865941	83.71	97	69.81	4827265	50.99
2	1.045	6911	100.00	34	4.304	344786	98.77	66	17.72	1874656	83.04	98	72.96	4922353	49.25
3	1.092	13822	100.00	35	4.498	372949	98.65	67	18.52	1865941	82.38	99	76.26	5155421	47.46
4	1.142	20733	99.99	36	4.702	412901	98.51	68	19.36	1867275	81.71	100	79.71	5355535	45.59
5	1.194	27644	99.98	37	4.914	460413	98.35	69	20.23	1878322	81.05	101	83.32	5636388	43.64
6	1.247	31099	99.97	38	5.137	531983	98.17	70	21.15	1886778	80.38	102	87.08	5925589	41.58
7	1.304	36471	99.96	39	5.369	585218	97.98	71	22.11	1896207	79.71	103	91.02	6058473	39.45
8	1.363	38958	99.94	40	5.612	658942	97.76	72	23.11	1935033	79.03	104	95.14	6299965	37.26
9	1.424	43952	99.93	41	5.865	760814	97.50	73	24.15	1973148	78.33	105	99.44	6542313	34.97
10	1.489	47752	99.91	42	6.131	833954	97.22	74	25.24	2071490	77.61	106	103.9	6850599	32.59
11	1.556	49483	99.90	43	6.408	920552	96.91	75	26.38	2191483	76.85	107	108.6	7021468	30.13
12	1.627	51832	99.88	44	6.698	1029300	96.56	76	27.58	2317720	76.05	108	113.5	7194496	27.60
13	1.700	56243	99.86	45	7.000	1128063	96.18	77	28.82	2381448	75.22	109	118.7	7246062	25.03
14	1.777	59950	99.84	46	7.317	1236812	95.76	78	30.13	2426416	74.36	110	124.1	7325533	22.44
15	1.857	68012	99.82	47	7.648	1332224	95.30	79	31.49	2581031	73.47	111	129.7	7221505	19.86
16	1.941	74792	99.79	48	7.994	1439092	94.81	80	32.91	2692284	72.54	112	135.5	6803050	17.36
17	2.029	76020	99.76	49	8.355	1516811	94.28	81	34.40	2709070	71.58	113	141.7	6512813	14.99
18	2.121	85854	99.73	50	8.733	1658615	93.72	82	35.96	2852014	70.59	114	148.1	6092864	12.75
19	2.217	86472	99.70	51	9.128	1732038	93.12	83	37.58	2965005	69.55	115	154.8	5422636	10.70
20	2.317	90991	99.67	52	9.541	1802846	92.49	84	39.28	3071056	68.48	116	161.8	5023716	8.844
21	2.422	96753	99.64	53	9.972	1865941	91.84	85	41.06	3174266	67.37	117	169.1	4535838	7.143
22	2.531	103663	99.60	54	10.42	1921229	91.16	86	42.92	3261942	66.23	118	176.7	3960719	5.632
23	2.646	110574	99.57	55	10.89	1948872	90.47	87	44.86	3373932	65.05	119	184.7	3648952	4.278
24	2.765	123954	99.52	56	11.39	1948872	89.78	88	46.89	3445751	63.83	120	193.1	3096080	3.078
25	2.891	136547	99.48	57	11.90	1954956	89.09	89	49.01	3548006	62.59	121	201.8	2721749	2.042
26	3.021	149684	99.43	58	12.44	1921229	88.40	90	51.22	3654433	61.31	122	210.9	1879763	1.223
27	3.158	168570	99.37	59	13.00	1907407	87.72	91	53.54	3812838	59.98	123	220.4	1271604	0.661
28	3.301	182409	99.31	60	13.59	1893585	87.04	92	55.96	3899087	58.61	124	230.4	663446	0.316
29	3.450	199136	99.24	61	14.20	1879763	86.37	93	58.49	3977245	57.21	125	240.8	387010	0.129
30	3.606	220615	99.17	62	14.85	1879763	85.70	94	61.13	4169398	55.76	126	251.7	165861	0.030
31	3.769	241544	99.08	63	15.52	1865941	85.04	95	63.90	4372025	54.24	127	263.1	0	0.000
32	3.939	272135	98.99	64	16.22	1865941	84.37	96	66.79	4564666	52.66				

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD
PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653   FAX: 312 832 5686

Date: Wed Mar 01 1989

Time: 9:59:42 a.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-4

Job No: ID-14966

Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

geometric mean size = 2.402   arithmetic mean size = 3.244
standard deviation = 3.983   coeff.of variation = 165.9
median size = 1.942   mode size = 1.287

Total = 3500511

Coincidence Corrected: No

FREQUENCY DISTRIBUTION DATA

Chnl	Size	Counts	% >	Chnl	Size	Counts	% >	Chnl	Size	Counts	% >	Chnl	Size	Counts	% >
1	1.000	0	100.0	32	3.939	41562	23.01	63	15.52	4664	1.136	94	61.13	171	0.046
2	1.045	56506	99.20	33	4.118	40946	21.83	64	16.22	4082	1.011	95	63.90	156	0.041
3	1.092	98967	96.99	34	4.304	40383	20.67	65	16.95	3573	0.902	96	66.79	142	0.037
4	1.142	130008	93.72	35	4.498	38252	19.55	66	17.72	3143	0.806	97	69.81	132	0.033
5	1.194	151806	89.70	36	4.702	37089	18.47	67	18.52	2742	0.722	98	72.96	117	0.029
6	1.247	149557	85.40	37	4.914	36219	17.42	68	19.36	2405	0.648	99	76.26	108	0.026
7	1.304	153600	81.07	38	5.137	36649	16.38	69	20.23	2117	0.584	100	79.71	98	0.023
8	1.363	143686	76.82	39	5.369	35304	15.35	70	21.15	1862	0.527	101	83.32	93	0.020
9	1.424	141961	72.74	40	5.612	34816	14.35	71	22.11	1638	0.477	102	87.08	83	0.018
10	1.489	135073	68.78	41	5.865	35202	13.35	72	23.11	1467	0.432	103	91.02	73	0.015
11	1.556	122578	65.10	42	6.131	33794	12.37	73	24.15	1310	0.393	104	95.14	68	0.013
12	1.627	112444	61.74	43	6.408	32665	11.42	74	25.24	1203	0.357	105	99.44	64	0.012
13.	1.700	106852	58.61	44	6.698	31985	10.49	75	26.38	1115	0.324	106	103.9	59	0.010
14	1.777	99739	55.65	45	7.000	30699	9.597	76	27.58	1031	0.293	107	108.6	49	0.008
15	1.857	99094	52.81	46	7.317	29477	8.738	77	28.82	929	0.265	108	113.5	44	0.007
16	1.941	95432	50.03	47	7.648	27806	7.919	78	30.13	826	0.240	109	118.7	39	0.006
17	2.029	84947	47.46	48	7.994	26305	7.146	79	31.49	772	0.217	110	124.1	34	0.005
18	2.121	84013	45.04	49	8.355	24281	6.423	80	32.91	704	0.196	111	129.7	29	0.004
19	2.217	74104	42.78	50	8.733	23249	5.744	81	34.40	621	0.177	112	135.5	24	0.003
20	2.317	68292	40.75	51	9.128	21265	5.108	82	35.96	572	0.160	113	141.7	20	0.002
21	2.422	63589	38.86	52	9.541	19383	4.527	83	37.58	523	0.144	114	148.1	20	0.002
22	2.531	59668	37.10	53	9.972	17569	3.999	84	39.28	474	0.130	115	154.8	15	0.001
23	2.646	55738	35.45	54	10.42	15843	3.521	85	41.06	430	0.117	116	161.8	10	0.001
24	2.765	54716	33.88	55	10.89	14074	3.094	86	42.92	386	0.105	117	169.1	10	0.001
25	2.891	52785	32.34	56	11.39	12324	2.717	87	44.86	347	0.095	118	176.7	5	0.001
26	3.021	50674	30.86	57	11.90	10828	2.386	88	46.89	313	0.086	119	184.7	5	0.000
27	3.158	49980	29.42	58	12.44	9317	2.098	89	49.01	284	0.077	120	193.1	5	0.000
28	3.301	47359	28.03	59	13.00	8100	1.849	90	51.22	254	0.069	121	201.8	5	0.000
29	3.450	45282	26.71	60	13.59	7044	1.632	91	53.54	230	0.062	122	210.9	0	0.000
30	3.606	43933	25.43	61	14.20	6125	1.444	92	55.96	205	0.056				
31	3.769	42124	24.21	62	14.85	5363	1.280	93	58.49	186	0.051				

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD

PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Wed Mar 01 1989

Time: 9:59:42 a.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-4

Job No: ID-14966

Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

PERCENTILES

0.10%	Volm	above	242.7	um
1.00%	Volm	above	213.7	um
6.00%	Volm	above	174.6	um
22.00%	Volm	above	124.8	um
50.00%	Volm	above	71.58	um
78.00%	Volm	above	24.61	um
94.00%	Volm	above	8.548	um
99.00%	Volm	above	3.922	um
99.90%	Volm	above	1.541	um

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD

PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Wed Mar 01 1989

Time: 9:59:42 a.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-4

Job No: ID-14966

Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

Low at 1 1.000 0 High at 127 263.1 0 Top of scale is 9830400

Graph of DIAM Size vs. Differential Volume From channel 1 to 127 skip: 2

Scale: 0 10 20 30 40 50 60 70 80 90 100

% >	Size
100.0	1.000
99.99	1.142
99.96	1.304
99.91	1.489
99.86	1.700
99.79	1.941
99.70	2.217
99.60	2.531
99.48	2.891
99.31	3.301
99.08	3.769
98.77	4.304
98.35	4.914
97.76	5.612
96.91	6.408
95.76	7.317
94.28	8.355
92.49	9.541
90.47	10.89
88.40	12.44
86.37	14.20
84.37	16.22
82.38	18.52
80.38	21.15
78.33	24.15
76.05	27.58
73.47	31.49
70.59	35.96
67.37	41.06
63.83	46.89
59.98	53.54
55.76	61.13
50.99	69.81
45.59	79.71
39.45	91.02
32.59	103.9
25.03	118.7
17.36	135.5
10.70	154.8
5.632	176.7
2.042	201.8
0.316	230.4
0.000	263.1

% > Size 0 10 20 30 40 50 60 70 80 90 100

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD
PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Wed Mar 01 1989

Time: 9:59:42 a.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-4

Job No: ID-14966

Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

Low at 1 1.000 0 High at 122 210.9 0 Top of scale is 153600

Graph of DIAM Size vs. Differential Counts From channel 1 to 121 skip: 2

% >	Size
100.0	1.000
93.72	1.142
81.07	1.304
68.78	1.489
58.61	1.700
50.03	1.941
42.78	2.217
37.10	2.531
32.34	2.891
28.03	3.301
24.21	3.769
20.67	4.304
17.42	4.914
14.35	5.612
11.42	6.408
8.738	7.317
6.423	8.355
4.527	9.541
3.094	10.89
2.098	12.44
1.444	14.20
1.011	16.22
0.722	18.52
0.527	21.15
0.393	24.15
0.293	27.58
0.217	31.49
0.160	35.96
0.117	41.06
0.086	46.89
0.062	53.54
0.046	61.13
0.033	69.81
0.023	79.71
0.015	91.02
0.010	103.9
0.006	118.7
0.003	135.5
0.001	154.8
0.001	176.7
0.000	201.8

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD

PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Wed Mar 01 1989

Time: 9:59:42 a.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-4

Job No: ID-14966

Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

PERCENTILES

0.10%	Popl	above	43.77	um
1.00%	Popl	above	16.27	um
6.00%	Popl	above	8.582	um
22.00%	Popl	above	4.088	um
50.00%	Popl	above	1.941	um
78.00%	Popl	above	1.345	um
94.00%	Popl	above	1.137	um
99.00%	Popl	above	1.050	um
99.90%	Popl	above	1.025	um

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD
PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Tue Feb 28 1989

Time: 3:06:31 p.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-6

Job No: ID-14966

Technician: L.W

Special Comments

geometric mean size = 6.797
standard deviation = 4.966
median size = 6.616

arithmetic mean size = 8.019
coeff.of variation = 73.06
mode size = 5.321

Total = 376504775

Coincidence Corrected: No

Extrapolated above: 1.619

VOLUME DISTRIBUTION DATA

Chnl	Size	Volume	% >	Chnl	Size	Volume	% >	Chnl	Size	Volume	% >	Chnl	Size	Volume	% >
1	1.000	34775	100.00	33	2.356	1187444	96.60	65	5.551	7220844	62.01	97	13.08	3643799	14.47
2	1.027	40125	99.99	34	2.420	1284838	96.27	66	5.702	7081624	60.11	98	13.43	3407063	13.53
3	1.055	46204	99.97	35	2.486	1397430	95.91	67	5.856	6962102	58.25	99	13.80	3227597	12.65
4	1.084	53135	99.96	36	2.553	1467587	95.53	68	6.015	6888418	56.41	100	14.17	3244741	11.79
5	1.113	60916	99.95	37	2.622	1583948	95.13	69	6.179	6804400	54.59	101	14.56	3025880	10.96
6	1.143	69792	99.93	38	2.694	1745176	94.69	70	6.346	6749441	52.79	102	14.95	2840091	10.18
7	1.174	79763	99.91	39	2.767	1893151	94.20	71	6.519	6714302	51.00	103	15.36	2926541	9.413
8	1.206	90949	99.89	40	2.842	2044165	93.68	72	6.696	6594414	49.23	104	15.78	2667677	8.670
9	1.239	103473	99.86	41	2.919	2178035	93.12	73	6.877	6567300	47.48	105	16.20	2558733	7.976
10	1.273	117577	99.83	42	2.998	2329901	92.52	74	7.064	6467961	45.75	106	16.64	2531861	7.300
11	1.307	133384	99.80	43	3.080	2509124	91.88	75	7.256	6323756	44.05	107	17.10	2537211	6.627
12	1.343	150893	99.76	44	3.163	2659895	91.19	76	7.453	6253356	42.38	108	17.56	2444438	5.965
13	1.379	170469	99.72	45	3.249	2785497	90.47	77	7.655	6187332	40.73	109	18.04	2360177	5.327
14	1.416	192112	99.67	46	3.337	2972502	89.70	78	7.863	6099058	39.10	110	18.53	2213783	4.720
15	1.455	216186	99.61	47	3.428	3177989	88.89	79	8.076	5970538	37.50	111	19.03	2162472	4.138
16	1.494	242693	99.55	48	3.521	3462022	88.01	80	8.295	5896125	35.92	112	19.54	1914794	3.597
17	1.535	271996	99.49	49	3.616	3826548	87.04	81	8.521	5777089	34.37	113	20.08	1839530	3.098
18	1.577	304217	99.41	50	3.715	3991910	86.00	82	8.752	5615618	32.86	114	20.62	1732045	2.624
19	1.619	339600	99.32	51	3.815	4150706	84.92	83	8.989	5445271	31.39	115	21.18	1504550	2.194
20	1.663	373523	99.23	52	3.919	4498817	83.77	84	9.233	5370128	29.95	116	21.75	1337608	1.816
21	1.709	433224	99.12	53	4.025	4881581	82.53	85	9.484	5252430	28.54	117	22.35	1208358	1.478
22	1.755	502044	99.00	54	4.135	5141905	81.19	86	9.741	5056305	27.17	118	22.95	1116071	1.169
23	1.803	561987	98.86	55	4.247	5329517	79.80	87	10.01	4905899	25.85	119	23.57	913625	0.899
24	1.851	615244	98.70	56	4.362	5843477	78.32	88	10.28	4837444	24.56	120	24.21	684793	0.687
25	1.902	674944	98.53	57	4.481	6199734	76.72	89	10.56	4694698	23.29	121	24.87	622539	0.513
26	1.953	746317	98.34	58	4.602	6413854	75.05	90	10.84	4577607	22.06	122	25.55	498031	0.364
27	2.006	790211	98.14	59	4.727	6506992	73.33	91	11.14	4441062	20.86	123	26.24	373523	0.248
28	2.061	809301	97.92	60	4.855	6844281	71.56	92	11.44	4274241	19.70	124	26.95	249016	0.166
29	2.117	917394	97.69	61	4.987	7041256	69.71	93	11.75	4184751	18.58	125	27.68	186762	0.108
30	2.174	956667	97.45	62	5.123	7239448	67.82	94	12.07	4014282	17.49	126	28.44	186762	0.058
31	2.233	1017462	97.18	63	5.262	7325533	65.88	95	12.40	3814389	16.45	127	29.21	62254	0.025
32	2.294	1105007	96.90	64	5.404	7311429	63.94	96	12.73	3730735	15.45	128	30.00	62254	0.008

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD
PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Tue Feb 28 1989

Time: 3:06:31 p.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-6

Job No: ID-14966

Technician: L.W

Special Comments

PERCENTILES

0.10%	Volm	above	27.79	um
1.00%	Volm	above	23.31	um
6.00%	Volm	above	17.53	um
22.00%	Volm	above	10.85	um
50.00%	Volm	above	6.617	um
78.00%	Volm	above	4.384	um
94.00%	Volm	above	2.795	um
99.00%	Volm	above	1.753	um
99.90%	Volm	above	1.186	um

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD
PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Tue Feb 28 1989

Time: 3:06:31 p.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-6

Job No: ID-14966

Technician: L.W

Special Comments

geometric mean size = 2.666
standard deviation = 2.853
median size = 2.537

arithmetic mean size = 3.206
coeff.of variation = 107.1
mode size = 1.950

Total = 8019373

Coincidence Corrected: No

Extrapolated above: 1.619

FREQUENCY DISTRIBUTION DATA

Chnl	Size	Counts	% >	Chnl	Size	Counts	% >	Chnl	Size	Counts	% >	Chnl	Size	Counts	% >
1	1.000	53340	99.67	33	2.356	139263	55.11	65	5.551	64750	8.926	97	13.08	2499	0.862
2	1.027	56795	98.98	34	2.420	139051	53.37	66	5.702	58600	8.156	98	13.43	2156	0.833
3	1.055	60350	98.25	35	2.486	139561	51.64	67	5.856	53163	7.459	99	13.80	1884	0.808
4	1.084	64045	97.48	36	2.553	135253	49.92	68	6.015	48540	6.825	100	14.17	1748	0.786
5	1.113	67756	96.66	37	2.622	134707	48.24	69	6.179	44247	6.246	101	14.56	1504	0.765
6	1.143	71636	95.79	38	2.694	136961	46.55	70	6.346	40501	5.718	102	14.95	1303	0.748
7	1.174	75549	94.87	39	2.767	137104	44.84	71	6.519	37179	5.233	103	15.36	1239	0.732
8	1.206	79494	93.90	40	2.842	136612	43.13	72	6.696	33697	4.791	104	15.78	1042	0.718
9	1.239	83458	92.89	41	2.919	134321	41.44	73	6.877	30967	4.388	105	16.20	923	0.705
10	1.273	87513	91.82	42	2.998	132594	39.78	74	7.064	28144	4.019	106	16.64	842	0.694
11	1.307	91614	90.70	43	3.080	131769	38.13	75	7.256	25392	3.685	107	17.10	779	0.684
12	1.343	95638	89.54	44	3.163	128904	36.50	76	7.453	23171	3.382	108	17.56	692	0.675
13	1.379	99706	88.32	45	3.249	124569	34.92	77	7.655	21157	3.106	109	18.04	617	0.667
14	1.416	103690	87.05	46	3.337	122670	33.38	78	7.863	19244	2.854	110	18.53	534	0.660
15	1.455	107675	85.73	47	3.428	121025	31.86	79	8.076	17385	2.626	111	19.03	481	0.653
16	1.494	111545	84.37	48	3.521	121664	30.35	80	8.295	15843	2.418	112	19.54	394	0.648
17	1.535	115362	82.95	49	3.616	124092	28.82	81	8.521	14325	2.230	113	20.08	349	0.643
18	1.577	119067	81.49	50	3.715	119461	27.30	82	8.752	12849	2.061	114	20.62	303	0.639
19	1.619	122655	79.98	51	3.815	114624	25.84	83	8.989	11498	1.909	115	21.18	243	0.636
20	1.663	124492	78.44	52	3.919	114646	24.41	84	9.233	10464	1.772	116	21.75	199	0.633
21	1.709	133243	76.84	53	4.025	114796	22.98	85	9.484	9444	1.648	117	22.35	166	0.631
22	1.755	142489	75.12	54	4.135	111583	21.57	86	9.741	8389	1.536	118	22.95	141	0.629
23	1.803	147188	73.31	55	4.247	106726	20.21	87	10.01	7512	1.437	119	23.57	107	0.627
24	1.851	148697	71.47	56	4.362	107984	18.87	88	10.28	6835	1.348	120	24.21	74	0.626
25	1.902	150532	69.60	57	4.481	105723	17.53	89	10.56	6121	1.267	121	24.87	62	0.625
26	1.953	153600	67.71	58	4.602	100931	16.25	90	10.84	5508	1.194	122	25.55	46	0.625
27	2.006	150079	65.81	59	4.727	94492	15.03	91	11.14	4931	1.129	123	26.24	31	0.624
28	2.061	141838	63.99	60	4.855	91716	13.87	92	11.44	4379	1.071	124	26.95	19	0.624
29	2.117	148370	62.18	61	4.987	87072	12.75	93	11.75	3957	1.019	125	27.68	14	0.624
30	2.174	142777	60.37	62	5.123	82611	11.69	94	12.07	3502	0.973	126	28.44	13	0.624
31	2.233	140128	58.60	63	5.262	77140	10.70	95	12.40	3071	0.932	127	29.21	4	0.623
32	2.294	140436	56.85	64	5.404	71048	9.773	96	12.73	2772	0.895	128	30.00	49998	0.314

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD

PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Tue Feb 28 1989

Time: 3:06:31 p.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-6

Job No: ID-14966

Technician: L.W

Special Comments

Low at 1 1.000 53340 High at 128 30.00 49998 Top of scale is 153600

Graph of DIAM Size vs. Differential Counts From channel 1 to 127 skip: 2

% >	Size
99.67	1.000
97.48	1.084
94.87	1.174
91.82	1.273
88.32	1.379
84.37	1.494
79.98	1.619
75.12	1.755
69.60	1.902
63.99	2.061
58.60	2.233
53.37	2.420
48.24	2.622
43.13	2.842
38.13	3.080
33.38	3.337
28.82	3.616
24.41	3.919
20.21	4.247
16.25	4.602
12.75	4.987
9.773	5.404
7.459	5.856
5.718	6.346
4.388	6.877
3.382	7.453
2.626	8.076
2.061	8.752
1.648	9.484
1.348	10.28
1.129	11.14
0.973	12.07
0.862	13.08
0.786	14.17
0.732	15.36
0.694	16.64
0.667	18.04
0.648	19.54
0.636	21.18
0.629	22.95
0.625	24.87
0.624	26.95
0.623	29.21

Scale: 0 10 20 30 40 50 60 70 80 90 100

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD
PARTICLE DATA, INC
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Date: Tue Feb 28 1989

Time: 3:06:31 p.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-6

Job No: ID-14966

Technician: L.W

Special Comments

PERCENTILES

0.10%	Popl	above	30.26	um
1.00%	Popl	above	11.87	um
6.00%	Popl	above	6.248	um
22.00%	Popl	above	4.100	um
50.00%	Popl	above	2.549	um
78.00%	Popl	above	1.675	um
94.00%	Popl	above	1.203	um
99.00%	Popl	above	1.026	um
99.90%	Popl	above	0.989	um

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD

PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Wed Mar 01 1989

Time: 12:45:03 p.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-2

Job No: ID-14966

Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

geometric mean size	= 61.45	arithmetic mean size	= 74.56
standard deviation	= 45.45	coeff.of variation	= 73.96
median size	= 66.62	mode size	= 87.74

Total = 338866636

Coincidence Corrected: No

VOLUME DISTRIBUTION DATA

Chnl	Size	Volume	% <	Chnl	Size	Volume	% <	Chnl	Size	Volume	% <	Chnl	Size	Volume	% <
1	3.000	0	0.000	33	9.189	322023	1.078	65	28.15	2922736	12.36	97	86.21	7325533	65.80
2	3.107	129	0.000	34	9.516	312866	1.172	66	29.15	3029435	13.24	98	89.28	7325533	67.96
3	3.217	535	0.000	35	9.855	358156	1.271	67	30.19	3193187	14.16	99	92.46	7286703	70.11
4	3.332	19447	0.003	36	10.21	397786	1.383	68	31.26	3484824	15.14	100	95.75	7208324	72.25
5	3.451	41139	0.012	37	10.57	428637	1.504	69	32.37	3725449	16.21	101	99.16	7076620	74.36
6	3.573	40414	0.024	38	10.95	478521	1.638	70	33.53	3856455	17.33	102	102.7	6972262	76.43
7	3.701	42347	0.036	39	11.34	498140	1.782	71	34.72	4103120	18.50	103	106.3	6739490	78.46
8	3.832	47451	0.049	40	11.74	510230	1.931	72	35.96	4312266	19.74	104	110.1	6446469	80.40
9	3.969	51656	0.064	41	12.16	535564	2.085	73	37.24	4420765	21.03	105	114.1	6212052	82.27
10	4.110	54365	0.080	42	12.59	629390	2.257	74	38.56	4634721	22.37	106	118.1	5977635	84.07
11	4.256	59476	0.096	43	13.04	616800	2.441	75	39.93	4748716	23.75	107	122.3	5450197	85.76
12	4.408	64731	0.115	44	13.50	692611	2.634	76	41.36	4971948	25.18	108	126.7	5157175	87.32
13	4.565	68600	0.134	45	13.98	781088	2.851	77	42.83	5246214	26.69	109	131.2	4805550	88.79
14	4.727	76518	0.156	46	14.48	873200	3.095	78	44.35	5328803	28.25	110	135.9	4453924	90.16
15	4.896	79539	0.179	47	15.00	926006	3.361	79	45.93	5450197	29.84	111	140.7	4043694	91.41
16	5.070	88584	0.204	48	15.53	947365	3.637	80	47.57	5829983	31.51	112	145.7	3809277	92.57
17	5.250	94087	0.231	49	16.08	995588	3.924	81	49.26	5964336	33.25	113	150.9	3399047	93.64
18	5.437	96646	0.259	50	16.65	1091418	4.232	82	51.01	6080354	35.02	114	156.3	3106026	94.60
19	5.631	108442	0.289	51	17.25	1240861	4.576	83	52.83	6243957	36.84	115	161.8	2813005	95.47
20	5.831	118723	0.323	52	17.86	1374492	4.961	84	54.71	6387865	38.71	116	167.6	2461379	96.25
21	6.039	129269	0.359	53	18.50	1346545	5.363	85	56.66	6622282	40.63	117	173.6	2109754	96.93
22	6.254	142971	0.399	54	19.16	1347837	5.760	86	58.68	6668542	42.59	118	179.7	1875336	97.51
23	6.477	145848	0.442	55	19.84	1477553	6.177	87	60.77	6798095	44.57	119	186.1	1699524	98.04
24	6.707	156017	0.486	56	20.54	1591053	6.630	88	62.93	6993492	46.61	120	192.8	1406502	98.50
25	6.946	168925	0.534	57	21.28	1669023	7.111	89	65.17	7032512	48.68	121	199.6	1172085	98.88
26	7.193	191070	0.587	58	22.03	1756976	7.616	90	67.49	7149720	50.77	122	206.7	996272	99.20
27	7.449	190484	0.644	59	22.82	1880114	8.153	91	69.89	7233434	52.89	123	214.1	861362	99.48
28	7.715	204454	0.702	60	23.63	2081197	8.737	92	72.38	7266929	55.03	124	221.7	637780	99.70
29	7.989	210363	0.763	61	24.47	2191831	9.367	93	74.96	7266929	57.18	125	229.6	354175	99.84
30	8.274	237137	0.829	62	25.34	2374818	10.04	94	77.63	7325533	59.33	126	237.8	234417	99.93
31	8.568	270389	0.904	63	26.24	2525970	10.76	95	80.39	7266929	61.48	127	246.2	117209	99.98
32	8.873	295114	0.987	64	27.18	2698535	11.53	96	83.25	7325533	63.63	128	255.0	0	100.0

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD
PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Wed Mar 01 1989

Time: 12:45:03 p.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-2

Job No: ID-14966

Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

Low at 1 3.000 0 High at 128 255.0 0 Top of scale is 9830400

Graph of DIAM Size vs. Differential Volume From channel 1 to 127 skip: 2

% <	Size
0.000	3.000
0.003	3.332
0.036	3.701
0.080	4.110
0.134	4.565
0.204	5.070
0.289	5.631
0.399	6.254
0.534	6.946
0.702	7.715
0.904	8.568
1.172	9.516
1.504	10.57
1.931	11.74
2.441	13.04
3.095	14.48
3.924	16.08
4.961	17.86
6.177	19.84
7.616	22.03
9.367	24.47
11.53	27.18
14.16	30.19
17.33	33.53
21.03	37.24
25.18	41.36
29.84	45.93
35.02	51.01
40.63	56.66
46.61	62.93
52.89	69.89
59.33	77.63
65.80	86.21
72.25	95.75
78.46	106.3
84.07	118.1
88.79	131.2
92.57	145.7
95.47	161.8
97.51	179.7
98.88	199.6
99.70	221.7
99.98	246.2

% < Size 0 10 20 30 40 50 60 70 80 90 100

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD

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Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-2

Job No: ID-14966

Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

PERCENTILES

0.10%	Volm	below	4.283	um
1.00%	Volm	below	8.911	um
6.00%	Volm	below	19.55	um
22.00%	Volm	below	38.19	um
50.00%	Volm	below	66.62	um
78.00%	Volm	below	105.5	um
94.00%	Volm	below	152.6	um
99.00%	Volm	below	201.8	um
99.90%	Volm	below	234.1	um

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD

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TEL: 312 832 5653 FAX: 312 832 5686

Date: Wed Mar 01 1989

Time: 12:45:03 p.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-2

Job No: ID-14966

Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

geometric mean size	= 7.917	arithmetic mean size	= 10.80
standard deviation	= 12.01	coeff.of variation	= 151.7
median size	= 6.598	mode size	= 3.497

Total = 4366752

Coincidence Corrected: No

FREQUENCY DISTRIBUTION DATA

Chnl	Size	Counts	% <	Chnl	Size	Counts	% <	Chnl	Size	Counts	% <	Chnl	Size	Counts	% <
1	3.000	0	0.000	31	8.568	65955	62.19	61	24.47	22976	91.31	91	69.89	3213	99.37
2	3.107	643	0.007	32	8.873	64830	63.69	62	25.34	22413	91.83	92	72.38	2972	99.45
3	3.217	2490	0.043	33	9.189	63705	65.16	63	26.24	21449	92.33	93	74.96	2651	99.51
4	3.332	80656	0.987	34	9.516	55672	66.53	64	27.18	20646	92.81	94	77.63	2410	99.57
5	3.451	153600	3.662	35	9.855	57439	67.82	65	28.15	20084	93.28	95	80.39	2169	99.62
6	3.573	135926	6.979	36	10.21	57439	69.14	66	29.15	18798	93.72	96	83.25	1928	99.67
7	3.701	128214	10.00	37	10.57	55672	70.43	67	30.19	17834	94.14	97	86.21	1767	99.71
8	3.832	129339	12.95	38	10.95	55993	71.71	68	31.26	17513	94.55	98	89.28	1607	99.75
9	3.969	126768	15.89	39	11.34	52459	72.95	69	32.37	16870	94.94	99	92.46	1446	99.78
10	4.110	120100	18.71	40	11.74	48362	74.11	70	33.53	15665	95.32	100	95.75	1285	99.81
11	4.256	118333	21.44	41	12.16	45710	75.19	71	34.72	15023	95.67	101	99.16	1125	99.84
12	4.408	115923	24.13	42	12.59	48362	76.26	72	35.96	14219	96.00	102	102.7	964	99.87
13	4.565	110621	26.72	43	13.04	42738	77.31	73	37.24	13175	96.32	103	106.3	884	99.89
14	4.727	111103	29.26	44	13.50	43140	78.29	74	38.56	12372	96.61	104	110.1	723	99.91
15	4.896	104033	31.72	45	13.98	43863	79.29	75	39.93	11408	96.88	105	114.1	643	99.92
16	5.070	104274	34.11	46	14.48	44104	80.29	76	41.36	10765	97.13	106	118.1	562	99.93
17	5.250	99695	36.44	47	15.00	42095	81.28	77	42.83	10283	97.38	107	122.3	482	99.95
18	5.437	92224	38.64	48	15.53	38802	82.21	78	44.35	9399	97.60	108	126.7	402	99.96
19	5.631	93188	40.77	49	16.08	36713	83.07	79	45.93	8596	97.81	109	131.2	321	99.97
20	5.831	91823	42.88	50	16.65	36231	83.91	80	47.57	8274	98.00	110	135.9	241	99.97
21	6.039	90055	44.97	51	17.25	37115	84.75	81	49.26	7632	98.18	111	140.7	241	99.98
22	6.254	89654	47.02	52	17.86	37034	85.60	82	51.01	6989	98.35	112	145.7	161	99.98
23	6.477	82343	48.99	53	18.50	32616	86.39	83	52.83	6507	98.50	113	150.9	161	99.99
24	6.707	79371	50.85	54	19.16	29403	87.10	84	54.71	5945	98.65	114	156.3	161	99.99
25	6.946	77362	52.64	55	19.84	29001	87.77	85	56.66	5623	98.78	115	161.8	80	99.99
26	7.193	78728	54.43	56	20.54	28117	88.43	86	58.68	5061	98.90	116	167.6	80	99.99
27	7.449	70695	56.14	57	21.28	26591	89.05	87	60.77	4659	99.01	117	173.6	80	100.00
28	7.715	68285	57.73	58	22.03	25225	89.65	88	62.93	4338	99.12	118	179.7	80	100.00
29	7.989	63304	59.24	59	22.82	24261	90.21	89	65.17	3936	99.21	119	186.1	80	100.00
30	8.274	64268	60.70	60	23.63	24181	90.77	90	67.49	3535	99.30	120	192.8	0	100.0

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD

PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Wed Mar 01 1989

Time: 12:45:03 p.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-2

Job No: ID-14966

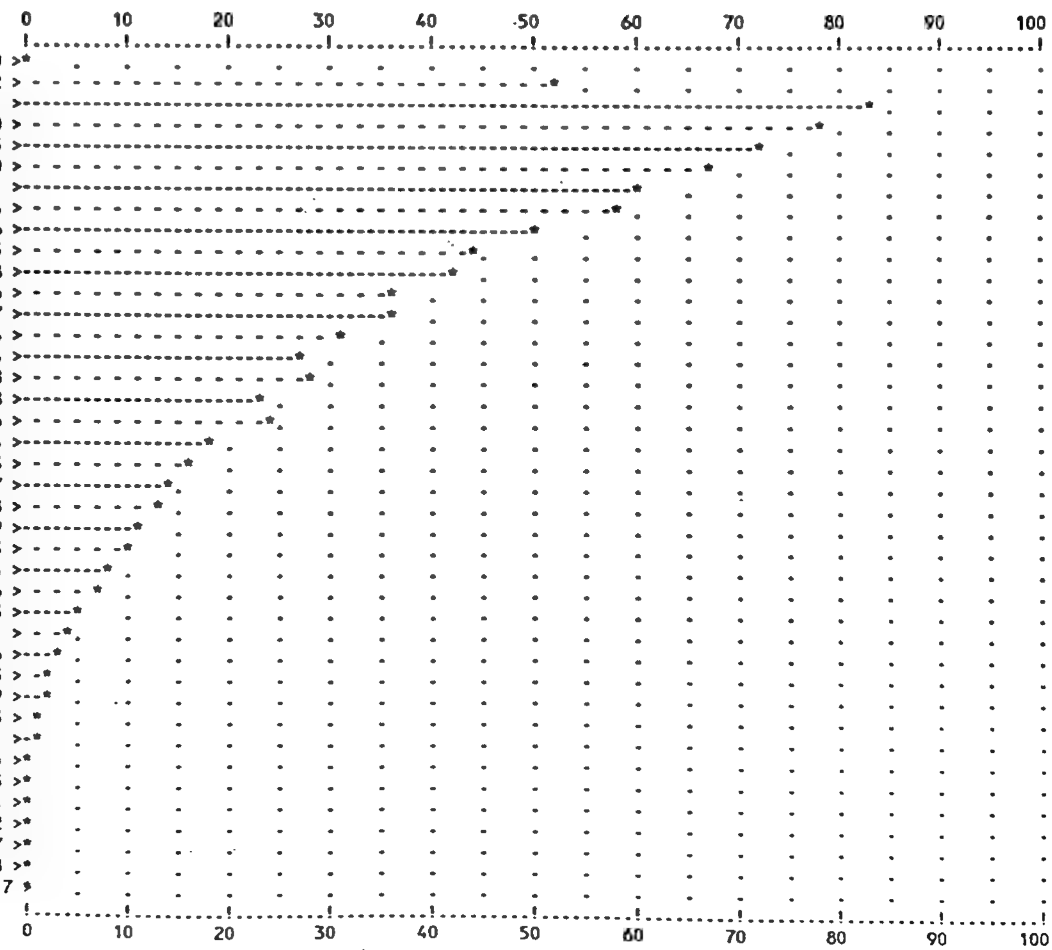
Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

Low at 1 3.000 0 High at 120 192.8 0 Top of scale is 153600

Graph of DIAM Size vs. Differential Counts From channel 1 to 118 skip: 2



% <	Size
0.000	3.000
0.987	3.332
10.00	3.701
18.71	4.110
26.72	4.565
34.11	5.070
40.77	5.631
47.02	6.254
52.64	6.946
57.73	7.715
62.19	8.568
66.53	9.516
70.43	10.57
74.11	11.74
77.31	13.04
80.29	14.48
83.07	16.08
85.60	17.86
87.77	19.84
89.65	22.03
91.31	24.47
92.81	27.18
94.14	30.19
95.32	33.53
96.32	37.24
97.13	41.36
97.81	45.93
98.35	51.01
98.78	56.66
99.12	62.93
99.37	69.89
99.57	77.63
99.71	86.21
99.81	95.75
99.89	106.3
99.93	118.1
99.97	131.2
99.98	145.7
99.99	161.8
100.00	179.7

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD
PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Wed Mar 01 1989

Time: 12:45:03 p.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-2

Job No: ID-14966

Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

PERCENTILES

0.10%	Popl	below	3.276	um
1.00%	Popl	below	3.331	um
6.00%	Popl	below	3.533	um
22.00%	Popl	below	4.283	um
50.00%	Popl	below	6.598	um
78.00%	Popl	below	13.36	um
94.00%	Popl	below	29.81	um
99.00%	Popl	below	60.47	um
99.90%	Popl	below	108.9	um

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD
PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653   FAX: 312 832 5686

Date: Fri Mar 01 1989

Time: 11:50:12 a.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-3

Job No: ID-14966

Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

geometric mean size	= 57.58	arithmetic mean size	= 77.99
standard deviation	= 57.34	coeff.of variation	= 99.58
median size	= 66.39	mode size	= 98.63

Total = 337169208

Coincidence Corrected: No

VOLUME DISTRIBUTION DATA

Chnl	Size	Volume	% >	Chnl	Size	Volume	% >	Chnl	Size	Volume	% >	Chnl	Size	Volume	% >
1	0.900	0	100.0	33	3.734	209832	99.16	65	15.49	1917287	91.31	97	64.25	6788260	51.51
2	0.941	59	100.00	34	3.903	217502	99.10	66	16.19	2057730	90.72	98	67.17	6996397	49.47
3	0.984	12503	100.00	35	4.081	239793	99.03	67	16.93	2148099	90.09	99	70.23	7125720	47.37
4	1.028	25007	99.99	36	4.266	258700	98.96	68	17.70	2237659	89.44	100	73.42	7050202	45.27
5	1.075	37511	99.98	37	4.460	271576	98.88	69	18.50	2313809	88.77	101	76.76	7148452	43.17
6	1.124	50014	99.97	38	4.663	285073	98.79	70	19.34	2407897	88.07	102	80.25	7131197	41.05
7	1.175	62518	99.95	39	4.875	308168	98.71	71	20.22	2479652	87.34	103	83.90	7259791	38.91
8	1.229	63741	99.94	40	5.097	332813	98.61	72	21.14	2610588	86.59	104	87.71	7279890	36.76
9	1.284	67042	99.92	41	5.328	366907	98.51	73	22.10	2760918	85.79	105	91.70	7157912	34.62
10	1.343	67139	99.90	42	5.571	390815	98.40	74	23.11	2882420	84.96	106	95.87	7295026	32.47
11	1.404	70481	99.88	43	5.824	422203	98.27	75	24.16	2947005	84.09	107	100.2	7325533	30.31
12	1.468	68952	99.85	44	6.089	464046	98.14	76	25.26	3064315	83.20	108	104.8	7216216	28.15
13	1.534	64279	99.83	45	6.365	497265	98.00	77	26.41	3229012	82.27	109	109.5	7156999	26.02
14	1.604	62517	99.82	46	6.655	518686	97.85	78	27.61	3404713	81.28	110	114.5	7094218	23.90
15	1.677	62517	99.80	47	6.957	579603	97.69	79	28.86	3582907	80.25	111	119.7	6968657	21.82
16	1.753	65333	99.78	48	7.274	605643	97.51	80	30.17	3797773	79.15	112	125.2	6889865	19.76
17	1.833	68054	99.76	49	7.604	681252	97.32	81	31.55	3969503	78.00	113	130.9	6748266	17.74
18	1.916	75021	99.74	50	7.950	702327	97.12	82	32.98	4175918	76.80	114	136.8	6529192	15.77
19	2.004	62517	99.72	51	8.312	798365	96.89	83	34.48	4350134	75.53	115	143.0	6278069	13.87
20	2.095	86456	99.70	52	8.689	850072	96.65	84	36.05	4606558	74.20	116	149.5	5964166	12.06
21	2.190	90244	99.67	53	9.085	900279	96.39	85	37.69	4887876	72.80	117	156.3	5752749	10.32
22	2.289	101899	99.64	54	9.498	1000372	96.11	86	39.40	5078963	71.32	118	163.4	5336359	8.672
23	2.394	108219	99.61	55	9.929	1050290	95.80	87	41.19	5260132	69.79	119	170.9	5007728	7.138
24	2.502	121453	99.58	56	10.38	1150208	95.48	88	43.06	5369557	68.21	120	178.6	4331868	5.751
25	2.616	121116	99.54	57	10.85	1250201	95.12	89	45.02	5609163	66.58	121	186.8	3955184	4.522
26	2.735	125585	99.50	58	11.35	1350182	94.74	90	47.07	5886306	64.88	122	195.3	3515719	3.413
27	2.859	133935	99.46	59	11.86	1450311	94.32	91	49.21	6098439	63.10	123	204.1	3076254	2.435
28	2.989	142124	99.42	60	12.40	1500811	93.88	92	51.45	6285426	61.26	124	213.4	2574008	1.596
29	3.125	162419	99.38	61	12.96	1600157	93.42	93	53.78	6362573	59.39	125	223.1	2008982	0.916
30	3.267	162540	99.33	62	13.55	1740401	92.93	94	56.23	6556782	57.47	126	233.3	1443956	0.403
31	3.416	186853	99.28	63	14.17	1790293	92.41	95	58.79	6676872	55.51	127	243.9	627807	0.094
32	3.571	199612	99.22	64	14.81	1850799	91.87	96	61.46	6755975	53.52	128	255.0	0	0.000

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD
PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Fri Mar 01 1989

Time: 11:50:12 a.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RHA-3

Job No: ID-14966

Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

Low at 1 0.900 0 High at 128 255.0 0 Top of scale is 9830400

Graph of DIAM Size vs. Differential Volume From channel 1 to 127 skip: 2

Scale: 0 10 20 30 40 50 60 70 80 90 100

% >	Size
100.0	0.900
99.99	1.028
99.95	1.175
99.90	1.343
99.83	1.534
99.78	1.753
99.72	2.004
99.64	2.289
99.54	2.616
99.42	2.989
99.28	3.416
99.10	3.903
98.88	4.460
98.61	5.097
98.27	5.824
97.85	6.655
97.32	7.604
96.65	8.689
95.80	9.929
94.74	11.35
93.42	12.96
91.87	14.81
90.09	16.93
88.07	19.34
85.79	22.10
83.20	25.26
80.25	28.86
76.80	32.98
72.80	37.69
68.21	43.06
63.10	49.21
57.47	56.23
51.51	64.25
45.27	73.42
38.91	83.90
32.47	95.87
26.02	109.5
19.76	125.2
13.87	143.0
8.672	163.4
4.522	186.8
1.596	213.4
0.094	243.9

% > Size 0 10 20 30 40 50 60 70 80 90 100

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD
PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Fri Mar 01 1989

Time: 11:50:12 a.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-3

Job No: ID-14966

Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

PERCENTILES

0.10%	Volm	above	243.3	um
1.00%	Volm	above	221.6	um
6.00%	Volm	above	177.0	um
22.00%	Volm	above	119.2	um
50.00%	Volm	above	66.38	um
78.00%	Volm	above	31.52	um
94.00%	Volm	above	12.25	um
99.00%	Volm	above	4.148	um
99.90%	Volm	above	1.329	um

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD
PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Fri Mar 01 1989

Time: 11:50:12 a.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-3

Job No: ID-14966

Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

geometric mean size	= 1.803	arithmetic mean size	= 2.419
standard deviation	= 3.667	coeff.of variation	= 203.4
median size	= 1.434	mode size	= 1.170

Total = 2064477

Coincidence Corrected: No

FREQUENCY DISTRIBUTION DATA

Chnl	Size	Counts	% >	Chnl	Size	Counts	% >	Chnl	Size	Counts	% >	Chnl	Size	Counts	% >
1	0.900	0	100.0	33	3.734	16075	11.92	65	15.49	2058	1.101	97	64.25	102	0.037
2	0.941	282	99.99	34	3.903	14583	11.18	66	16.19	1933	1.005	98	67.17	92	0.032
3	0.984	52373	98.73	35	4.081	14069	10.48	67	16.93	1766	0.915	99	70.23	81	0.028
4	1.028	91670	95.25	36	4.266	13284	9.819	68	17.70	1610	0.833	100	73.42	71	0.024
5	1.075	120336	90.13	37	4.460	12203	9.202	69	18.50	1457	0.759	101	76.76	63	0.021
6	1.124	140412	83.82	38	4.663	11211	8.634	70	19.34	1326	0.691	102	80.25	54	0.018
7	1.175	153600	76.70	39	4.875	10606	8.106	71	20.22	1196	0.630	103	83.90	48	0.016
8	1.229	137051	69.66	40	5.097	10023	7.606	72	21.14	1102	0.575	104	87.71	44	0.014
9	1.284	126149	63.28	41	5.328	9670	7.129	73	22.10	1019	0.523	105	91.70	38	0.012
10	1.343	110557	57.54	42	5.571	9015	6.676	74	23.11	931	0.476	106	95.87	33	0.010
11	1.404	101568	52.40	43	5.824	8522	6.252	75	24.16	833	0.433	107	100.2	29	0.008
12	1.468	86956	47.83	44	6.089	8196	5.847	76	25.26	758	0.395	108	104.8	25	0.007
13	1.534	70941	44.00	45	6.365	7687	5.462	77	26.41	699	0.359	109	109.5	21	0.006
14	1.604	60381	40.82	46	6.655	7017	5.105	78	27.61	645	0.327	110	114.5	19	0.005
15	1.677	52842	38.08	47	6.957	6862	4.769	79	28.86	595	0.297	111	119.7	17	0.004
16	1.753	48327	35.62	48	7.274	6276	4.451	80	30.17	551	0.269	112	125.2	15	0.003
17	1.833	44053	33.39	49	7.604	6178	4.149	81	31.55	503	0.243	113	130.9	13	0.003
18	1.916	42500	31.29	50	7.950	5572	3.865	82	32.98	463	0.220	114	136.8	10	0.002
19	2.004	30994	29.51	51	8.312	5545	3.595	83	34.48	424	0.199	115	143.0	8	0.002
20	2.095	37510	27.85	52	8.689	5165	3.336	84	36.05	392	0.179	116	149.5	6	0.001
21	2.190	34264	26.11	53	9.085	4787	3.095	85	37.69	363	0.160	117	156.3	6	0.001
22	2.289	33859	24.46	54	9.498	4656	2.866	86	39.40	332	0.144	118	163.4	4	0.001
23	2.394	31468	22.88	55	9.929	4278	2.649	87	41.19	301	0.128	119	170.9	4	0.001
24	2.502	30907	21.37	56	10.38	4100	2.446	88	43.06	267	0.115	120	178.6	2	0.000
25	2.616	26971	19.96	57	10.85	3900	2.253	89	45.02	244	0.102	121	186.8	2	0.000
26	2.735	24474	18.72	58	11.35	3685	2.069	90	47.07	225	0.091	122	195.3	2	0.000
27	2.859	22844	17.57	59	11.86	3466	1.896	91	49.21	205	0.080	123	204.1	2	0.000
28	2.989	21213	16.50	60	12.40	3138	1.736	92	51.45	184	0.071	124	213.4	2	0.000
29	3.125	21215	15.48	61	12.96	2927	1.589	93	53.78	163	0.063	125	223.1	0	0.000
30	3.267	18581	14.51	62	13.55	2787	1.450	94	56.23	146	0.055				
31	3.416	18691	13.61	63	14.17	2509	1.322	95	58.79	132	0.048				
32	3.571	17474	12.73	64	14.81	2269	1.206	96	61.46	117	0.042				

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD
PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Fri Mar 01 1989

Time: 11:50:12 a.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-3

Job No: ID-14966

Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

Low at 1 0.900 0 High at 125 223.1 0 Top of scale is 153600

Graph of DIAM Size vs. Differential Counts From channel 1 to 124 skip: 2

% >	Size
100.0	0.900
95.25	1.028
76.70	1.175
57.54	1.343
44.00	1.534
35.62	1.753
29.51	2.004
24.46	2.289
19.96	2.616
16.50	2.989
13.61	3.416
11.18	3.903
9.202	4.460
7.606	5.097
6.252	5.824
5.105	6.655
4.149	7.604
3.336	8.689
2.649	9.929
2.069	11.35
1.589	12.96
1.206	14.81
0.915	16.93
0.691	19.34
0.523	22.10
0.395	25.26
0.297	28.86
0.220	32.98
0.160	37.69
0.115	43.06
0.080	49.21
0.055	56.23
0.037	64.25
0.024	73.42
0.016	83.90
0.010	95.87
0.006	109.5
0.003	125.2
C.002	143.0
0.001	163.4
0.000	186.8
0.000	213.4

Scale: 0 10 20 30 40 50 60 70 80 90 100

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD

PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Fri Mar 01 1989

Time: 11:50:12 a.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-3

Job No: ID-14966

Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

PERCENTILES

0.10%	Popl	above	45.33	um
1.00%	Popl	above	16.21	um
6.00%	Popl	above	5.983	um
22.00%	Popl	above	2.455	um
50.00%	Popl	above	1.432	um
78.00%	Popl	above	1.165	um
94.00%	Popl	above	1.040	um
99.00%	Popl	above	0.978	um
99.90%	Popl	above	0.963	um

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD
PARTICLE DATA, INC
111 HAHN ST., ELMHURST, IL 60126
TEL: 312 832 5653 FAX: 312 832 5686

Date: Thu Feb 28 1989

Time: 3:51:23 p.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-1

Job No: ID-14966

Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

geometric mean size = 47.35
standard deviation = 50.94
median size = 51.75

arithmetic mean size = 64.66
coeff.of variation = 107.6
mode size = 56.73

Total = 412905380

Coincidence Corrected: No

Extrapolated below: 3.415

VOLUME DISTRIBUTION DATA

Chnl	Size	Volume	% <	Chnl	Size	Volume	% <	Chnl	Size	Volume	% <	Chnl	Size	Volume	% <
1	2.000	25439	0.003	33	6.792	888817	2.338	65	23.06	4211798	19.46	97	78.32	6831788	68.91
2	2.078	29390	0.010	34	7.056	990156	2.565	66	23.96	4467470	20.51	98	81.37	6787895	70.56
3	2.159	33892	0.017	35	7.331	1026124	2.809	67	24.89	4659944	21.62	99	84.54	6672659	72.19
4	2.243	39011	0.026	36	7.616	1101370	3.067	68	25.86	4789846	22.76	100	87.83	6674434	73.81
5	2.330	44820	0.036	37	7.913	1158289	3.340	69	26.87	4926498	23.94	101	91.25	6589775	75.41
6	2.421	51397	0.048	38	8.221	1275467	3.635	70	27.92	5108942	25.15	102	94.80	6465069	76.99
7	2.515	58830	0.061	39	8.541	1320236	3.949	71	29.01	5299800	26.41	103	98.50	6264684	78.54
8	2.613	67212	0.077	40	8.874	1348106	4.272	72	30.13	5523270	27.72	104	102.3	6010556	80.02
9	2.715	76645	0.094	41	9.220	1537468	4.621	73	31.31	5630896	29.07	105	106.3	5677103	81.44
10	2.821	87239	0.114	42	9.579	1618461	5.003	74	32.53	5799673	30.46	106	110.5	5842513	82.83
11	2.931	99113	0.136	43	9.952	1686211	5.403	75	33.79	5863831	31.87	107	114.8	5591192	84.22
12	3.045	112394	0.162	44	10.34	1796881	5.825	76	35.11	6060522	33.31	108	119.2	5416556	85.55
13	3.163	127216	0.191	45	10.74	1823832	6.263	77	36.48	6335984	34.81	109	123.9	5231019	86.84
14	3.286	143724	0.224	46	11.16	1919160	6.717	78	37.90	6366516	36.35	110	128.7	5125372	88.09
15	3.414	162073	0.261	47	11.59	2055316	7.198	79	39.37	6510759	37.91	111	133.7	4985622	89.32
16	3.547	219067	0.307	48	12.05	2088458	7.700	80	40.91	6636345	39.50	112	138.9	4650596	90.49
17	3.686	229763	0.361	49	12.52	2139100	8.211	81	42.50	6815479	41.13	113	144.3	4575512	91.60
18	3.829	257804	0.420	50	13.00	2193642	8.736	82	44.16	6906219	42.79	114	149.9	4337451	92.68
19	3.978	279499	0.485	51	13.51	2231645	9.272	83	45.88	7066206	44.48	115	155.8	4235890	93.72
20	4.133	328673	0.559	52	14.04	2276582	9.818	84	47.66	7164618	46.21	116	161.9	3735103	94.69
21	4.294	348064	0.641	53	14.58	2302318	10.37	85	49.52	7245624	47.95	117	168.2	3656186	95.58
22	4.461	368741	0.727	54	15.15	2433740	10.95	86	51.45	7319708	49.72	118	174.7	3203367	96.41
23	4.635	411603	0.822	55	15.74	2531782	11.55	87	53.45	7321644	51.49	119	181.5	3006721	97.17
24	4.816	449521	0.926	56	16.35	2640063	12.17	88	55.53	7323585	53.26	120	188.6	2542108	97.84
25	5.003	486358	1.039	57	16.99	2728981	12.82	89	57.69	7325533	55.04	121	195.9	2161122	98.41
26	5.198	526108	1.162	58	17.65	2867105	13.50	90	59.94	7308408	56.81	122	203.5	1810368	98.89
27	5.400	560203	1.294	59	18.34	3044468	14.22	91	62.28	7265593	58.57	123	211.5	1497347	99.29
28	5.611	603970	1.434	60	19.05	3221965	14.97	92	64.70	7249953	60.33	124	219.7	1081793	99.60
29	5.829	665768	1.588	61	19.79	3426551	15.78	93	67.22	7124793	62.07	125	228.3	615917	99.81
30	6.056	721100	1.756	62	20.57	3610718	16.63	94	69.84	7161307	63.80	126	237.2	298118	99.92
31	6.292	767400	1.936	63	21.37	3790277	17.53	95	72.56	7119730	65.53	127	246.4	173372	99.98
32	6.537	829486	2.129	64	22.20	3982098	18.47	96	75.38	6973851	67.24	128	256.0	6917	100.00

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD

PARTICLE DATA, INC

111 HAHN ST., ELMHURST, IL 60126

TEL: 312 832 5653 FAX: 312 832 5686

Date: Thu Feb 28 1989

Time: 3:51:23 p.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-1

Job No: ID-14966

Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

Low at 1 2.000 25439 High at 128 256.0 6917 Top of scale is 9830400

Graph of DIAM Size vs. Differential Volume From channel 1 to 127 skip: 2

% <	Size
0.003	2.000
0.026	2.243
0.061	2.515
0.114	2.821
0.191	3.163
0.307	3.547
0.485	3.978
0.727	4.461
1.039	5.003
1.434	5.611
1.936	6.292
2.565	7.056
3.340	7.913
4.272	8.874
5.403	9.952
6.717	11.16
8.211	12.52
9.818	14.04
11.55	15.74
13.50	17.65
15.78	19.79
18.47	22.20
21.62	24.89
25.15	27.92
29.07	31.31
33.31	35.11
37.91	39.37
42.79	44.16
47.95	49.52
53.26	55.53
58.57	62.28
63.80	69.84
68.91	78.32
73.81	87.83
78.54	98.50
82.83	110.5
86.84	123.9
90.49	138.9
93.72	155.8
96.41	174.7
98.41	195.9
99.60	219.7
99.98	246.4

Scale: 0 10 20 30 40 50 60 70 80 90 100

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD
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Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-1

Job No: ID-14966

Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

PERCENTILES

0.10%	Volm	below	2.746	um
1.00%	Volm	below	4.938	um
6.00%	Volm	below	10.48	um
22.00%	Volm	below	25.19	um
50.00%	Volm	below	51.71	um
78.00%	Volm	below	97.15	um
94.00%	Volm	below	157.2	um
99.00%	Volm	below	205.3	um
99.90%	Volm	below	234.6	um

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD
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Date: Thu Feb 28 1989

Time: 3:51:23 p.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-1

Job No: ID-14966

Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

geometric mean size = 5.338
standard deviation = 36.84
median size = 4.427

arithmetic mean size = 11.48
coeff.of variation = 690.2
mode size = 3.590

Total = 5403924

Coincidence Corrected: No

Extrapolated below: 3.415

FREQUENCY DISTRIBUTION DATA

Chnl	Size	Counts	% <	Chnl	Size	Counts	% <	Chnl	Size	Counts	% <	Chnl	Size	Counts	% <
1	2.000	99532	0.912	33	6.792	88813	71.97	65	23.06	10751	95.64	97	78.32	443	97.84
2	2.078	102548	2.782	34	7.056	88223	73.61	66	23.96	10161	95.83	98	81.37	393	97.85
3	2.159	105448	4.706	35	7.331	81520	75.18	67	24.89	9457	96.01	99	84.54	344	97.86
4	2.243	108218	6.683	36	7.616	78029	76.65	68	25.86	8670	96.18	100	87.83	311	97.86
5	2.330	110873	8.709	37	7.913	73178	78.05	69	26.87	7949	96.33	101	91.25	279	97.87
6	2.421	113381	10.78	38	8.221	71850	79.39	70	27.92	7342	96.48	102	94.80	229	97.87
7	2.515	115724	12.90	39	8.541	66311	80.67	71	29.01	6802	96.61	103	98.50	213	97.88
8	2.613	117888	15.07	40	8.874	60378	81.85	72	30.13	6310	96.73	104	102.3	180	97.88
9	2.715	119887	17.26	41	9.220	61410	82.97	73	31.31	5736	96.84	105	106.3	148	97.89
10	2.821	121674	19.50	42	9.579	57641	84.08	74	32.53	5277	96.94	106	110.5	131	97.89
11	2.931	123264	21.77	43	9.952	53560	85.10	75	33.79	4753	97.04	107	114.8	115	97.89
12	3.045	124640	24.06	44	10.34	50889	86.07	76	35.11	4376	97.12	108	119.2	98	97.89
13	3.163	125804	26.38	45	10.74	46054	86.97	77	36.48	4081	97.20	109	123.9	82	97.89
14	3.286	126738	28.71	46	11.16	43218	87.79	78	37.90	3655	97.27	110	128.7	82	97.90
15	3.414	127443	31.07	47	11.59	41268	88.58	79	39.37	3343	97.33	111	133.7	66	97.90
16	3.547	153600	33.66	48	12.05	37400	89.30	80	40.91	3032	97.39	112	138.9	49	97.90
17	3.686	143652	36.41	49	12.52	34155	89.97	81	42.50	2786	97.45	113	144.3	49	97.90
18	3.829	143734	39.07	50	13.00	31238	90.57	82	44.16	2508	97.50	114	149.9	33	97.90
19	3.978	138964	41.69	51	13.51	28337	91.12	83	45.88	2294	97.54	115	155.8	33	97.90
20	4.133	145717	44.32	52	14.04	25780	91.62	84	47.66	2065	97.58	116	161.9	33	97.90
21	4.294	137604	46.95	53	14.58	23240	92.08	85	49.52	1868	97.62	117	168.2	16	97.90
22	4.461	129983	49.42	54	15.15	21912	92.50	86	51.45	1688	97.65	118	174.7	16	97.90
23	4.635	129377	51.82	55	15.74	20323	92.89	87	53.45	1508	97.68	119	181.5	16	97.90
24	4.816	126001	54.18	56	16.35	18897	93.25	88	55.53	1344	97.71	120	188.6	16	97.90
25	5.003	121559	56.48	57	16.99	17422	93.59	89	57.69	1196	97.73	121	195.9	16	97.90
26	5.198	117265	58.69	58	17.65	16324	93.90	90	59.94	1065	97.75	122	203.5	0	97.90
27	5.400	111332	60.80	59	18.34	15455	94.19	91	62.28	934	97.77	123	211.5	0	97.90
28	5.611	107038	62.82	60	19.05	14586	94.47	92	64.70	836	97.79	124	219.7	0	97.90
29	5.829	105219	64.79	61	19.79	13833	94.73	93	67.22	738	97.80	125	228.3	0	97.90
30	6.056	101613	66.70	62	20.57	12997	94.98	94	69.84	656	97.81	126	237.2	0	97.90
31	6.292	96434	68.53	63	21.37	12161	95.22	95	72.56	590	97.82	127	246.4	0	97.90
32	6.537	92943	70.29	64	22.20	11391	95.43	96	75.38	508	97.83	128	256.0	113364	98.94

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD
PARTICLE DATA, INC
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Time: 3:51:23 p.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-1

Job No: ID-14966

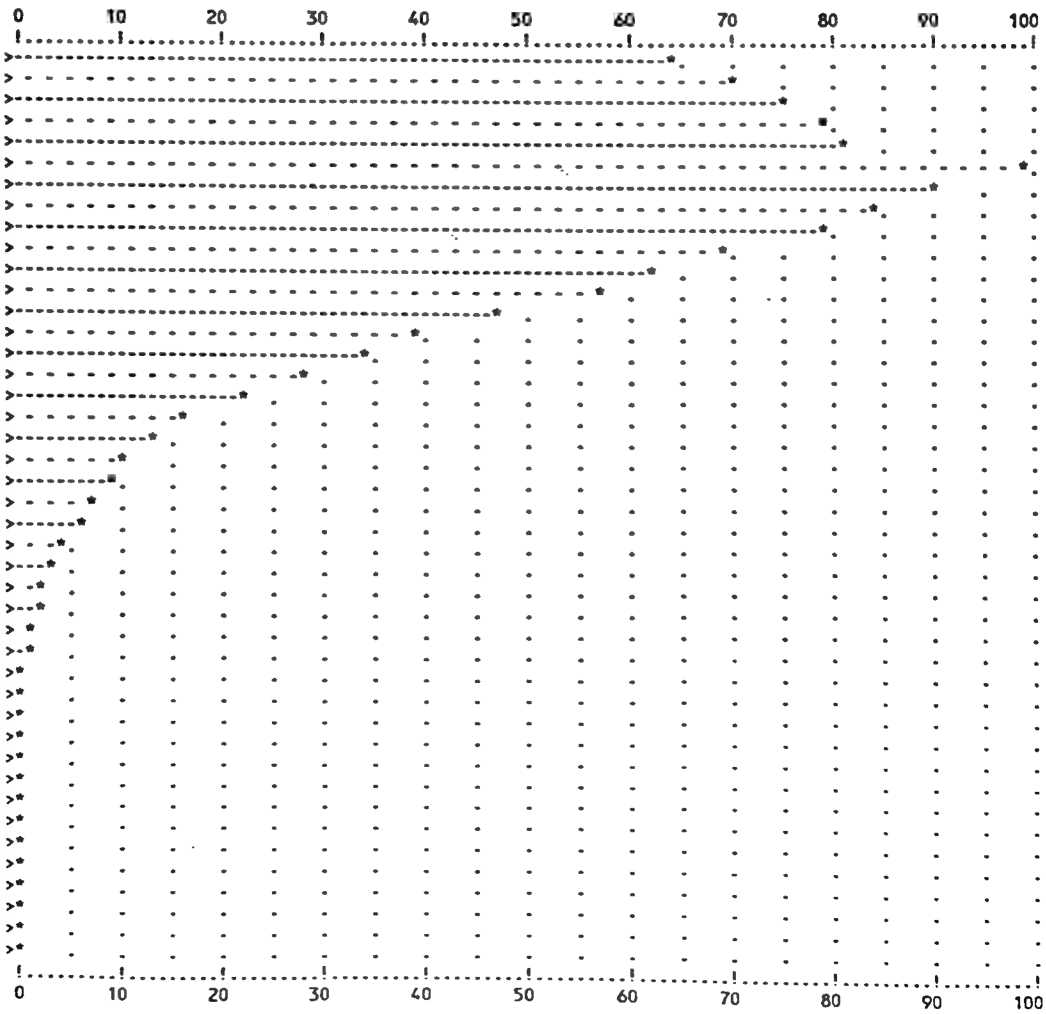
Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

Low at 1 2.000 99532 High at 128 256.0 113364 Top of scale is 153600

Graph of DIAM Size vs. Differential Counts From channel 1 to 127 skip: 2



% <	Size
0.912	2.000
6.683	2.243
12.90	2.515
19.50	2.821
26.38	3.163
33.66	3.547
41.69	3.978
49,42	4.461
56.48	5.003
62.82	5.611
68.53	6.292
73.61	7.056
78.05	7.913
81.85	8.874
85.10	9.952
87.79	11.16
89.97	12.52
91.62	14.04
92.89	15.74
93.90	17.65
94.73	19.79
95.43	22.20
96.01	24.89
96.48	27.92
96.84	31.31
97.12	35.11
97.33	39.37
97.50	44.16
97.62	49.52
97.71	55.53
97.77	62.28
97.81	69.84
97.84	78.32
97.86	87.83
97.88	98.50
97.89	110.5
97.89	123.9
97.90	138.9
97.90	155.8
97.90	174.7
97.90	195.9
97.90	219.7
97.90	246.4

PARTICLE SIZE ANALYSIS BY ELETROZONE METHOD

PARTICLE DATA, INC
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TEL: 312 832 5653 FAX: 312 832 5686

Date: Thu Feb 28 1989

Time: 3:51:23 p.m.

Client: U.S. ARMY ENGINEERS.

Sample Number: RMA-1

Job No: ID-14966

Technician: L.W

Special Comments

SAMPLE SIVED AT 250 MICRONS.

PERCENTILES

0.10%	Popl	below	1.964	um
1.00%	Popl	below	1.982	um
6.00%	Popl	below	2.213	um
22.00%	Popl	below	2.940	um
50.00%	Popl	below	4.498	um
78.00%	Popl	below	7.896	um
94.00%	Popl	below	17.86	um
99.00%	Popl	below	256.1	um
99.90%	Popl	below	260.1	um

APPENDIX B: MICROBIOLOGICAL METHODS

Materials and Methods

Media composition

Fermenter medium: Trypticase soy 2 g/ℓ, glucose 3 g/ℓ, mineral salts 100 ml/ℓ, phenol red 10 mg/ℓ, pH to 7.2.

Sulfate reducer/facultative: Trypticase soy 3 g/ℓ, Na lactate 10 mM, HEPES buffer 10 mM, $FeSO_4$ 100 μl of 2.5 percent stock solution/ℓ, resazurin add stock till faint blue, mineral salts 100 ml/ℓ, Hutner's mineral base 10 ml/ℓ, pH to 7.2, reduce with sulfide free cysteine HCl and oxygen free nitrogen.

Heterotrophic aerotolerant medium: Trypticase soy 500 mg/ℓ, Na succinate 300 mg/ℓ, 150 mg/ℓ filter sterilized yeast extract, mineral salts 100 ml/ℓ, Hutner's mineral base 10 ml/ℓ.

Mineral salts: NH_4Cl 20 mM, Na_2PO_4 2 mM.

Hutner's mineral base: As formulated in Manual of Methods for General Bacteriology.

MPN procedure

The 5 tube Most Probable number method was used to evaluate numbers of Heterotrophic Aerotolerant bacteria, Facultative bacteria, Sulfate Reducing bacteria and Fermenting bacteria. This method is outlined in Standard Methods for the Examination of Water and Waste Water, 14th edition. The formula for calculation used is found in the Manual of Methods for General Bacteriology. A basic program was developed by Heather Allison to run on an IBM PC computer in this laboratory.

Membrane filtration method

The membrane filtration method was used to enumerate fungi, as published in Manual of Methods for General Bacteriology. Gelman GA filters, 0.2 μm porosity, were used for these evaluations.

Epifluorescence acridine orange photomicroscopy

Samples were fixed on collection with the addition of formalin (1 percent v/v). Samples were stained for 5 min with acridine orange (final concentration 10 mg/ml) prior to filtration onto Nuclepore filters (irgalan black stained, 0.2 μm porosity). A Nikon epifluorescent microscope was used for photomicroscopy.

APPENDIX C: UNREDUCED SUSPENDED SOLIDS DATA

Table C1

North Boundary Treatment System Solids Mass Balance Analysis RMA

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
1A	Well No. 19	9-21-88	1532	1.47011	300	1.47013	0.07
B				1.47255	300	1.47262	0.23
C				1.47648	300	1.47652	0.13
2A	Well No. 19	9-22-88	1533	1.46836	300	1.46820	-0.53
B				1.47372	300	1.47350	-0.73
C				1.47629	300	1.47623	-0.20
3A	Well No. 19	9-23-88	1435	1.47270	200	1.47250	-1.00
B				1.47540	200	1.47530	-0.50
C				1.47648	200	1.47630	-0.90
4A	Well No. 19	9-20-88	1643	1.47362	300	1.47360	-0.07
B				1.47481	300	1.47485	0.13
C				1.47831	300	1.47825	-0.20
5A	Well No. 19	9-19-88	1700	1.47720	100	1.47707	-1.30
B				1.47507	100	1.47486	-2.10
C				1.47378	100	1.47353	-2.50
6A	Well No. 21	9-20-88	1650	1.47707	300	1.47700	-0.23
B				1.48099	300	1.48096	-0.10
C				1.47944	300	1.47945	0.03
7A	Well No. 21	9-23-88	1439	1.47548	200	1.47540	-0.40
B				1.47994	200	1.47972	-1.10
C				1.47592	200	1.47597	0.25

(Continued)

(Sheet 1 of 23)

Table C1 (Continued)

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
8A	Well No. 21	9-19-88	1705	1.48046	300	1.48043	-0.10
B				1.47929	300	1.47920	-0.30
C				1.47693	300	1.47681	-0.40
9A	Well No. 21	9-22-88	1538	1.47053	300	1.47042	-0.37
B				1.47428	300	1.47426	-0.08
C				1.47497	300	1.47486	-0.37
10A	Well No. 21	9-21-88	1538	1.47966	300	1.47960	-0.20
B				1.47729	300	1.47724	-0.17
C				1.47976	300	1.47974	0.07
11A	Well No. 24	9-22-88	1542	1.48107	300	1.48108	0.03
B				1.47781	300	1.47777	-0.13
C				1.47853	300	1.47846	-0.23
12A	Well No. 24	9-19-88	1630,1711	1.47814	300	1.47825	0.37
B				1.48514	300	1.48513	-0.03
C				1.48203	300	1.48237	1.13
13A	Well No. 24	9-23-88	1545	1.51001	300	1.51098	3.23
B				1.51118	300	1.51139	0.70
C				1.50968	300	1.51056	2.93
14A	Well No. 24	9-23-88	1444	1.50652	300	1.50662	0.33
B				1.50026	300	1.50038	0.40
C				1.50005	300	1.50015	0.33

(Continued)

(Sheet 2 of 23)

Table C1 (Continued)

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
15A	Well No. 24	9-20-88	1657	1.49829	300	1.49837	0.27
B				1.47564	300	1.49567	0.10
C				1.51174	300	1.51179	0.17
16A	Carbon Wash	9-20-88	1125	1.50973	100	1.51211	23.80
B				1.51098	100	1.51305	20.70
C				1.49498	100	1.49734	23.60
17A	Wash	9-16-88	1000	1.47315	300	1.47359	1.47
B				1.47433	300	1.47483	1.67
C				1.47245	300	1.47293	1.60
18A	Wash	9-16-88	1000	1.47070	300	1.47301	7.70
B				1.46932	300	1.47157	7.50
C				1.46869	300	1.47124	8.50
19A	A-Wash	9-16-88	1000	1.46455	300	1.46671	7.20
B				1.46712	300	1.46927	7.17
C				1.46755	300	1.46943	6.27
20A	RC-25	9-16-88	1400	1.46700	300	1.46701	0.03
B				1.46888	300	1.46888	0.00
C				1.47288	300	1.47297	0.30
21A	CW-13A	9-13-88	1140	1.47088	100	1.52351	526.30
B				1.46195	100	1.51392	519.70
C				1.46512	100	1.51347	483.50

(Continued)

(Sheet 3 of 23)

Table C1 (Continued)

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
22A	CW-13B	9-13-88	1140	1.46566	100	1.46804	23.80
B				1.46779	100	1.47004	22.50
C				1.46294	100	1.46528	23.40
23A	13	--	--	1.66388	600	1.66514	2.10
B				1.67037	600	1.67175	2.30
C				1.67300	600	1.67461	2.68
24A	18	9-13-88	1550	1.46080	100	1.46446	36.60
B				1.46460	100	1.46856	39.60
C				1.47028	100	1.47393	36.50
25A	21	9-16-88	1320	1.47012	300	1.47042	1.00
B				1.46774	300	1.46794	0.67
C				1.46425	300	1.46450	0.83
26A	21	9-14-88	1450	1.46443	100	1.46749	30.60
B				1.47248	100	1.47517	26.90
C				1.47181	100	1.47491	31.00
27A	21	9-15-88	1500	1.46486	300	1.46512	0.87
B				1.47088	300	1.47112	0.80
C				1.46456	300	1.46476	0.67
28A	22	9-16-88	1320	1.47336	300	1.47368	1.07
B				1.46638	300	1.46663	0.83
C				1.46431	300	1.46457	0.87

(Continued)

(Sheet 4 of 23)

Table C1 (Continued)

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
29A	22	9-15-88	1500	1.48259	300	1.48266	0.23
B				1.46810	300	1.46848	1.27
C				1.46904	300	1.46965	2.03
30A	22	9-14-88	1450	1.47363	300	1.47435	2.40
B				1.46850	300	1.46954	3.47
C				1.46795	300	1.46806	0.37
31A	12	9-13-88	1420	1.47234	300	1.47250	0.53
B				1.47609	300	1.47616	0.23
C				1.47293	300	1.47339	1.53
32A	12	9-14-88	1452	1.47104	300	1.47106	0.07
B				1.47480	300	1.47482	0.07
C				1.47786	300	1.47786	0.00
33A	12	9-15-88	1500	1.47356	300	1.47357	0.03
B				1.47365	300	1.47365	0.00
C				1.47436	300	1.47440	0.13
34A	12	9-16-88	1400	1.47596	300	1.47596	0.00
B				1.47116	300	1.47117	0.03
C				1.47442	300	1.47451	0.30
35A	11	9-22-88	1515	1.51337	900	1.51343	0.07
B				1.51066	900	1.51067	0.01
C				1.51000	900	1.51013	0.14

(Continued)

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Table C1 (Continued)

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
36A	11	9-23-88	1455	1.50764	900	1.50770	0.07
B				1.51221	900	1.51226	0.06
C				1.51490	900	1.51498	0.09
37A	11	9-15-88	1500	1.51458	900	1.51348	-1.22
B				1.51080	900	1.51261	2.01
C				1.51321	900	1.51208	-1.26
38A	11	9-21-88	0840	1.51669	900	1.51756	0.97
B				1.51385	900	1.51516	1.46
C				1.50743	900	1.50882	1.54
39A	11	9-14-88	1450	1.50621	900	1.50662	0.46
B				1.51193	900	1.51222	0.32
C				1.50803	900	1.50853	0.56
40A	11	9-21-88	1518	1.51639	600	1.51700	1.02
B				1.51603	600	1.51677	1.07
C				1.51737	600	1.51806	1.15
41A	11	9-22-88	0850	1.51754	900	1.51791	0.41
B				1.51349	900	1.51366	0.19
C				1.51898	900	1.51920	0.24
42A	11	9-16-88	0900	1.70220	600	1.70252	0.53
B				1.68226	600	1.68310	1.40
C				1.68361	600	1.68418	0.95

(Continued)

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Table C1 (Continued)

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
43A	11	9-16-88	1618	1.65491	600	1.65483	-0.13
B				1.67442	600	1.67440	-0.03
C				1.67564	600	1.67558	-0.10
44A	11	9-15-88	0920	1.67227	600	1.67223	-0.07
B				1.67883	600	1.67883	0.00
C				1.66596	600	1.66597	0.02
45A	11	9-23-88	0905	1.68700	900	1.68682	-0.20
B				1.51193	900	1.66380	-0.14
C				1.67049	900	1.67043	-0.07
46A	11	9-16-88	1320	1.66267	600	1.66321	0.90
B				1.66265	600	1.66308	0.72
C				1.65580	600	1.65640	1.00
47A	11	9-13-88	1000	1.68061	300	1.68100	1.30
B				1.66282	300	1.66332	1.67
C				1.67425	300	1.67476	1.70
48A	RC-10	9-13-88	1000	1.66985	300	1.67027	1.40
B				1.67185	300	1.67232	1.57
C				1.66090	300	1.66313	7.43
49A	RC-10 IN	9-16-88	1400	1.66363	900	1.66328	-0.39
B				1.67337	900	1.67308	-0.32
C				1.67422	900	1.67400	-0.24

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Table C1 (Continued)

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
50A	No. 10	9-15-88	0920	1.68137	600	1.68194	0.95
B				1.67354	600	1.67386	0.53
C				1.66695	600	1.66731	0.60
51A	No. 10	9-23-88	1421	1.64377	900	1.64402	0.28
B				1.67115	900	1.67155	0.44
C				1.68667	900	1.68690	0.26
52A	No. 10	9-22-88	1510	1.67817	900	1.67853	0.40
B				1.68419	900	1.68444	0.28
C				1.66093	900	1.66155	0.24
53A	No. 10	9-14-88	1450	1.67554	900	1.67568	0.16
B				1.65794	900	1.65805	0.12
C				1.67156	900	1.67173	0.19
54A	No. 10	9-20-88	1505	1.66507	900	1.66521	0.16
B				1.68567	900	1.68596	0.32
C				1.69620	900	1.69653	0.37
55A	No. 10	9-13-88	1000	1.67507	300	1.67567	2.00
B				1.68461	300	1.68537	2.53
C				1.66415	300	1.66494	2.63
55A	No. 10	9-15-88	1500	1.65573	900	1.65649	0.84
B				1.70038	900	1.70101	0.70
C				1.64916	900	1.64896	0.78

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Table C1 (Continued)

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
57A	No. 10	9-16-88	1320	1.66774	900	1.66795	0.23
B				1.67181	900	1.67194	0.14
C				1.66900	900	1.66922	0.24
58A	No. 9-C	9-19-88	0905	1.65477	600	1.65505	0.47
B				1.68888	600	1.68915	0.45
C				1.67686	600	1.67725	0.65
59A	No. 9-C	9-19-88	1615	1.66347	600	1.66407	1.00
B				1.67015	600	1.67075	1.00
C				1.66966	600	1.67042	1.27
60A	No. 9-C	9-21-88	0830	1.69925	600	1.70053	2.13
B				1.67731	600	1.67812	0.35
C				1.65617	600	1.65687	1.17
61A	No. 9-C	9-20-88	1510	1.66812	600	1.66827	0.25
B				1.66360	600	1.66366	0.10
C				1.69300	600	1.69308	0.13
62A	No. 9	9-22-88	1525	1.66325	600	1.66446	2.02
B				1.65104	600	1.65235	2.18
C				1.70376	600	1.70463	1.45
63A	No. 9	9-23-88	1500	1.68566	600	1.68572	0.10
B				1.67656	600	1.67657	0.02
C				1.69665	600	1.69685	0.33

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Table C1 (Continued)

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
64A	No. 9	9-22-88	0855	1.69783	600	1.69754	-0.48
B				1.66599	600	1.66583	-0.27
C				1.68428	600	1.68400	-0.47
65A	No. 9	9-14-88	1450	1.67461	600	1.67442	-0.32
B				1.65447	600	1.65433	-0.23
C				1.67155	600	1.67144	-0.18
66A	No. 9	9-23-88	0900	1.66865	900	1.66832	-0.37
B				1.68821	900	1.68801	-0.22
C				1.66731	900	1.66707	-0.27
67A	No. 9	9-13-88	1000	1.67674	300	1.67714	1.33
B				1.68581	300	1.68592	0.37
C				1.63905	300	1.63919	0.47
68A	No. 9	9-15-88	1500	1.65965	600	1.65966	0.02
B				1.68567	600	1.68554	-0.22
C				1.68913	600	1.68899	-0.23
69A	No. 9	9-16-88	1320	1.66557	600	1.66543	-0.23
B				1.66050	600	1.66035	-0.25
C				1.66740	600	1.66728	-0.20
70A	No. 8-B	9-21-88	0830	1.68141	900	1.68146	0.06
B				1.68702	900	1.68705	0.03
C				1.66247	900	1.66257	0.11

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Table C1 (Continued)

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
71A	No. 8-B	9-20-88	1510	1.67047	600	1.67073	0.43
B				1.69645	600	1.69680	0.58
C				1.67590	600	1.67620	0.50
72A	No. 8-B	9-19-88	--	1.67970	600	1.68026	0.93
B				1.68651	600	1.65433	1.45
C				1.65789	600	1.67144	1.30
73A	No. 8-B	9-19-88	1615	1.67426	900	1.67524	1.09
B				1.68700	900	1.68783	0.92
C				1.67710	900	1.67800	1.00
74A	Well No. 8	9-22-88	1530	1.68743	900	1.68778	0.39
B				1.67026	900	1.67064	0.42
C				1.65338	900	1.65356	0.20
75A	Well No. 8	9-23-88	1430	1.68365	900	1.68390	0.28
B				1.66695	900	1.66729	0.38
C				1.68677	900	1.68701	0.27
76A	Well No. 8	9-22-88	1525	1.67016	600	1.67104	1.47
B				1.66872	600	1.66952	1.33
C				1.69016	600	1.69105	1.48
77A	Well No. 8	9-23-88	1455	1.68777	600	1.68805	0.47
B				1.68894	600	1.68916	0.37
C				1.67935	600	1.67968	0.55

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Table C1 (Continued)

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
78A	No. 8	9-15-88	1500	1.67127	600	1.67200	1.22
B				1.67914	600	1.67989	1.25
C				1.68001	600	1.68086	1.42
79A	No. 8	9-23-88	0900	1.66353	600	1.66437	1.40
B				1.67732	600	1.67824	1.53
C				1.67884	600	1.67963	1.32
80A	8	9-13-88	1000	1.67937	300	1.68077	4.67
B				1.66367	300	1.66597	7.67
C				1.68556	300	1.68699	4.77
81A	8	9-14-88	1450	1.68405	600	1.68940	1.42
B				1.67702	600	1.67786	1.40
C				1.63700	600	1.63787	1.45
82A	8	9-22-88	0855	1.66630	900	1.66663	0.37
B				1.68732	900	1.68757	0.28
C				1.67141	900	1.67166	0.28
83A	Well No. 8	9-21-88	1526	1.68030	600	1.68053	0.38
B				1.67612	600	1.67653	0.68
C				1.66586	600	1.66612	0.43
84A	Well No. 8	9-19-88	1630,1718	1.67944	600	1.68000	0.93
B				1.63891	600	1.63937	0.77
C				1.66094	600	1.66167	1.22

(Continued)

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Table C1 (Continued)

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
85A	Well No. 8	9-20-88	1635	1.66700	600	1.66836	1.10
B				1.65977	600	1.66053	1.27
C				1.67030	600	1.67099	1.15
86A	8	9-16-88	1320	1.68605	600	1.68636	0.52
B				1.68717	600	1.68752	0.58
C				1.65266	600	1.65309	0.72
87A	2	9-19-88	1630	1.65998	900	1.66020	0.24
B				1.65886	900	1.65907	0.23
C				1.65811	900	1.65840	0.32
88A	2	9-13-88	1000	1.66583	100	1.71067	448.40
B				1.65522	100	1.69566	404.40
C				1.66541	100	1.70947	440.60
89A	2	9-21-88	1500	1.67477	600	1.67569	1.53
B				1.67856	600	1.67759	1.58
C				1.67828	600	1.67953	2.08
90A	2	9-15-88	1500	1.67988	600	1.68020	0.53
B				1.67722	600	1.67759	0.62
C				1.67675	600	1.67703	0.47
91A	No. 2	9-22-88	1520	1.65946	600	1.65948	0.03
B				1.65582	600	1.65590	0.13
C				1.65751	600	1.65752	0.02

(Continued)

Table C1 (Continued)

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
92A	No. 2	9-14-88	1450	1.65800	600	1.65812	0.20
B				1.68166	600	1.68174	0.13
C				1.66492	600	1.66504	0.20
93A	No. 2	9-23-88	1425	1.66535	600	1.66555	0.33
B				1.67121	600	1.67145	0.40
C				1.66931	600	1.66959	0.47
94A	No. 2	9-16-88	1320	1.66420	600	1.66436	0.27
B				1.66490	600	1.66504	0.23
C				1.67124	600	1.67143	0.32
95A	No. 3	9-23-88	1425	1.66962	600	1.66967	0.08
B				1.66744	600	1.66745	0.02
C				1.67081	600	1.67086	0.08
96A	No. 3	9-14-88	1450	1.66086	300	1.66210	4.13
B				1.68322	300	1.68452	4.33
C				1.67542	300	1.67665	4.10
97A	No. 3	9-21-88	1500	1.66896	900	1.66755	-1.57
B				1.68084	900	1.68379	3.28
C				1.66808	900	1.67022	2.38
98A	No. 3	9-19-88	1630	1.67084	600	1.67165	1.35
B				1.66828	600	1.66902	1.23
C				1.68820	600	1.68891	1.18

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Table C1 (Continued)

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
99A	No. 3	9-15-88	1500	1.68445	600	1.68485	0.67
B				1.67039	600	1.67096	0.95
C				1.66706	600	1.66738	0.53
100A	No. 3	9-16-88	1320	1.68212	600	1.68261	0.82
B				1.67442	600	1.67486	0.73
C				1.67622	600	1.67654	0.53
101A	No. 3	9-22-88	1520	1.67308	300	1.67629	10.70
B				1.67943	300	1.68235	9.73
C				1.67876	300	1.68180	10.43
102A	No. 3	9-13-88	1000	1.67399	100	1.69275	187.60
B				1.66139	100	1.67780	164.10
C				1.65534	100	1.67688	215.40
103A	5	9-13-88	1000	1.66933	300	1.67016	2.77
B				1.66102	300	1.66175	2.43
C				1.66619	300	1.66699	2.67
104A	5	9-15-88	1500	1.66575	600	1.66642	1.12
B				1.67320	600	1.67377	0.95
C				1.67947	600	1.68115	2.80
105A	5	9-14-88	1450	1.68105	600	1.68134	0.48
B				1.66828	600	1.67482	0.87
C				1.68820	600	1.66416	0.85

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Table C1 (Continued)

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
106A	5	9-15-88	1500	1.68266	900	1.68296	0.33
B				1.67523	900	1.67551	0.31
C				1.67560	900	1.67584	0.27
107A	5	9-16-88	1320	1.68263	600	1.68266	0.05
B				1.66763	600	1.66772	0.15
C				1.66103	600	1.66104	0.02
108A	6	9-13-88	1000	1.66794	600	1.66926	2.20
B				1.67375	600	1.67534	2.65
C				1.68593	600	1.68780	3.12
109A	6	9-14-88	1450	1.68583	900	1.68628	0.50
B				1.68014	900	1.68073	0.66
C				1.67143	900	1.67183	0.44
110A	6	9-16-88	1320	1.67650	900	1.67684	0.38
B				1.68600	900	1.68619	0.21
C				1.67051	900	1.67075	0.27
111A	7	9-14-88	1450	1.66638	900	1.66669	0.34
B				1.66123	900	1.66178	0.61
C				1.67880	900	1.67924	0.49
112A	7	9-23-88	1455	1.66972	900	1.67026	0.60
B				1.66399	900	1.66438	0.43
C				1.67101	900	1.67149	0.53

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Table C1 (Continued)

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
113A	7	9-15-88	0900	1.66763	600	1.66848	1.42
B				1.67126	600	1.67201	1.25
C				1.67470	600	1.67566	1.60
114A	7	9-22-88	1525	1.66640	600	1.66693	0.88
B				1.68110	600	1.68156	0.77
C				1.68033	600	1.68065	0.53
115A	7	9-15-88	1500	1.67960	900	1.68017	0.63
B				1.66793	900	1.66837	0.49
C				1.66231	900	1.66260	0.32
116A	7	9-16-88	1320	1.66539	900	1.66569	0.33
B				1.67316	900	1.67354	0.42
C				1.66614	900	1.66650	0.40
117A	7	9-13-88	1000	1.66130	300	1.66258	4.27
B				1.64931	300	1.65051	4.00
C				1.67608	300	1.67699	3.03
118A	7	9-23-88	0900	1.66171	900	1.66223	0.58
B				1.66286	900	1.66353	0.74
C				1.65374	900	1.65434	0.67
119A	7	9-13-88	1410	1.66276	900	1.66352	0.84
B				1.66328	900	1.66422	1.04
C				1.65122	900	1.65206	0.93

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Table C1 (Continued)

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
120A	7	9-22-88	0855	1.65284	900	1.65347	0.70
B				1.65947	900	1.66012	0.72
C				1.65866	900	1.65953	0.97
121A	No. 7-A	9-21-88	0830	1.66194	900	1.66238	0.49
B				1.65878	900	1.65956	0.87
C				1.64898	900	1.64949	0.57
122A	No. 7-A	9-19-88	1615	1.65606	900	1.65683	0.86
B				1.65968	900	1.66042	0.82
C				1.66623	900	1.66700	0.86
123A	No. 7-A	9-20-88	1510	1.65946	600	1.65968	0.37
B				1.66490	600	1.66558	1.13
C				1.66902	600	1.66974	1.20
124A	No. 7-A	9-19-88	0905	1.66844	600	1.66918	1.23
B				1.67062	600	1.67127	1.08
C				1.65633	600	1.65714	1.35
125A	No. 1	9-23-88	1425	1.67285	300	1.67330	1.50
B				1.67602	300	1.67668	2.20
C				1.66349	300	1.66384	1.17
126A	No. 1	9-16-88	1320	1.65879	300	1.65906	0.90
B				1.66432	300	1.66442	0.33
C				1.67216	300	1.67238	0.73

(Continued)

Table C1 (Continued)

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
127A	No. 1	9-15-88	1500	1.67185	300	1.67520	11.17
B				1.66391	300	1.66443	1.73
C				1.66925	300	1.66989	2.13
128A	No. 1	9-21-88	1500	1.67277	300	1.67447	5.67
B				1.67106	300	1.67284	5.93
C				1.65927	300	1.66155	7.60
129A	No. 1	9-19-88	1630	1.67422	300	1.67443	0.70
B				1.64898	300	1.64900	0.07
C				1.64405	300	1.64418	0.43
130A	No. 1	9-16-88	0930	1.65126	300	1.65164	1.27
B				1.66446	300	1.66499	1.77
C				1.66087	300	1.66113	0.87
131A	No. 1	9-13-88	1000	1.65838	100	1.69121	328.30
B				1.66461	100	1.69859	339.80
C				1.66503	100	1.69720	321.70
132A	No. 1	9-22-88	1520	1.65430	200	1.65463	1.65
B				1.65396	200	1.65440	2.20
C				1.65458	200	1.65520	3.10
133A	No. 4	9-16-88	1320	1.66182	300	1.66225	1.43
B				1.66583	300	1.66632	1.63
C				1.65738	300	1.65776	1.27

(Continued)

(Sheet 19 of 23)

Table C1 (Continued)

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
134A	No. 4	9-15-88	1500	1.66228	300	1.66253	0.83
B				1.65358	300	1.65391	1.17
C				1.66984	300	1.67051	2.23
135A	No. 4	9-14-88	1450	1.65732	500	1.65750	0.36
B				1.66422	500	1.66444	0.44
C				1.65942	500	1.65944	0.04
136A	No. 4	9-13-88	1000	1.67551	300	1.67699	4.93
B				1.65113	300	1.65262	4.97
C				1.66397	300	1.66564	5.57
137A	20	9-16-88	1500	1.66408	300	1.66476	2.27
B				1.66100	300	1.66150	1.67
C				1.66414	300	1.66470	1.87
138A	20	9-16-88	1320	1.67107	300	1.67142	1.17
B				1.66900	300	1.66906	0.20
C				1.66686	300	1.66696	0.33
139A	20	9-16-88	0930	1.67518	200	1.67571	2.65
B				1.67054	200	1.67100	2.30
C				1.67003	200	1.67078	3.75
140A	20	9-14-88	1450	1.68323	500	1.69071	14.96
B				1.66799	500	1.67499	14.00
C				1.65122	500	1.66069	18.94

(Continued)

(Sheet 20 of 23)

Table C1 (Continued)

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
141A	No. 1	9-14-88	1450	1.68746	600	1.68795	0.82
B				1.65765	600	1.65812	0.78
C				1.67645	600	1.67683	0.63
		Repeat of samples 11-7-88					
3A	Well No. 19	9-13-88	1435	1.68917	400	1.68932	0.38
B				1.64320	400	1.64345	0.63
5A	Well No. 19	9-19-88	1700	1.67427	500	1.67459	0.64
B				1.66479	500	1.66499	0.40
10A	Well No. 21	9-21-88	1538	1.65741	600	1.65778	0.62
B				1.67465	600	1.67460	-0.08
C				1.67395	600	1.67412	0.28
37A	11	9-15-88	1500	1.66220	300	1.66209	-0.37
B				1.68966	300	1.68971	0.17
68A	9	9-15-88	1500	1.66538	800	1.66591	0.66
B				1.65583	800	1.65640	0.71
		Repeat of Samples 11-9-88					
Samples were weighed, dried, and reweighed three times to determine a constant weight.							
2A	Well No. 19	9-22-88	1533	1.67004	600	1.67137	2.22
B				1.65147	600	1.65174	0.45

(Continued)

(Sheet 21 of 23)

Table C1 (Continued)

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
4A	Well No. 19	9-20-88	1643	1.68934	600	1.69001	1.12
B				1.66662	600	1.66713	0.85
7A	Well No. 21	9-13-88	1439	1.67016	400	1.67030	0.35
B				1.67341	400	1.67344	0.08
9A	Well No. 21	9-22-88	1538	1.69322	400	1.69355	0.83
B				1.65379	400	1.65356	-0.58
11A	Well No. 24	9-22-88	1542	1.69127	600	1.69200	1.22
B				1.65845	600	1.65887	0.70
127A	No. 1	9-15-88	1500	1.69028	600	1.69134	1.77
B				1.67654	600	1.67764	1.83
2A	Well No. 19	9-22-88	1533	1.67004	600		
B				1.65147	600	1.65173	0.43
4A	Well No. 19	9-20-88	1643	1.68934	600	1.69011	1.28
B				1.66662	600	1.67721	0.98
7A	Well No. 21	9-13-88	1439	1.67016	400	1.67035	0.48
B				1.67341	400	1.67349	0.20
9A	Well No. 21	9-22-88	1538	1.69322	400	1.69360	0.95
B				1.65379	400	1.65357	-0.55

(Continued)

(Sheet 22 of 23)

Table C1 (Concluded)

Lab ID Number	Sample Description	Date	Time	Tare Weight g	Volume Filtered ml	Dry Weight g	Suspended Solids mg/ℓ
11A	Well No. 24	9-22-88	1542	1.69127	600	1.69196	1.15
B				1.65845	600	1.65886	0.68
127A	No. 1	9-15-88	1500	1.69028	600	1.69138	1.83
B				1.67654	600	1.67766	1.87
2A	Well No. 19	9-13-88	1533	1.67004	600		
B				1.65147	600	1.65162	0.25
4A	Well No. 19	9-20-88	1643	1.68934	600	1.69000	1.10
B				1.66662	600	1.66707	0.75
7A	Well No. 21	9-13-88	1439	1.67016	400	1.67027	0.28
B				1.67341	400	1.67340	-0.03
9A	Well No. 21	9-22-88	1538	1.69322	400	1.69353	0.78
B				1.65379	400	1.65352	-0.68
11A	Well No. 24	9-22-88	1542	1.69127	600	1.69180	0.88
B				1.65845	600	1.65872	0.45
127A	No. 1	9-15-88	1500	1.69028	600	1.69122	1.57
B				1.67654	600	1.67765	1.85

(Sheet 23 of 23)

APPENDIX D: AVERAGE WEEKLY RECHARGE WELL WATER VOLUMES

Total Volume Recharged through North Boundary Recharge Wells (Gallons)

Week / Well	1 Aug 3	2 Aug 10	3 Aug 17	4 Aug 24	5 Aug 31	6 Sep 7	7 Sep 14	8 Sep 21	9 Sep 28	10 Oct 5	12 Oct 19	13 Oct 26	14 Nov 2	Avg
1	21903	2983	2975	3059	3053	3079	3048	2973	2500	2345	2794	2979	2893	4353
2	27963	30934	32162	31652	24350	23033	25414	20040	15833	10411	32892	34333	33689	26362
3	10778	6281	8098	2259	2469	5299	4417	16430	1759	2411	1243	1426	1992	4989
4	5166	4249	3711	3347	3182	3876	3857	4775	4323	37198	5430	48826	5911	10296
5	14745	13490	12800	11059	11056	9619	8226	6693	4473	4514	4286	4325	3767	8389
6	3912	2609	2448	1883	1954	2369	1847	1921	1840	2082	1799	1829	1846	2180
7	10293	9256	8137	7355	6255	5728	4964	4442	3847	3836	4647	4681	4463	5993
8	13447	12663	11997	11356	10544	11767	970	9541	11794	9277	22166	22792	25119	13341
9	8064	9237	9042	8876	8161	10976	75254	14179	5300	8326	252	16	7	12130
10	9990	7695	5958	4599	3463	2949	2542	2011	1745	2505	1937	1893	1804	3776
11	69516	101107	128460	148498	188636	162096	156183	171965	121698	80331	43575	21936	3495	107500
12	33080	30065	27116	24935	22653	21129	19034	16289	14136	14111	10965	9836	8778	19394
13	25906	269491	22333	21532	18087	16777	13216	9950	9146	9869	6772	5887	5282	33404
14	23693	23646	22431	21246	19271	17939	15712	12519	10633	1586	15	37	6	12980
15	28175	29270	29560	29046	26957	27058	26151	22909	20089	22565	27234	22638	493	24011
16	43602	87638	142207	158315	142485	145359	159092	181235	231140	257505	378167	407841	4203	179907
17	45988	140921	339114	369072	381183	367129	381910	346493	344618	375127	434190	431515	428245	337347
18	177246	212181	193461	212776	215415	204506	213517	192687	194693	213432	246735	247721	251589	213535
19	254298	305149	278314	302226	309360	286929	294234	282614	279967	301689	358163	363465	361567	306006
20	249766	294591	256381	272839	310697	299965	311050	288243	272751	289795	360019	345739	335008	299680
21	234634	282093	255643	280536	277970	259019	261568	266468	268365	285960	282037	107627	95173	242853
22	7908	92231	97473	97139	89515	80799	74813	62865	56071	61418	70140	65179	58160	70285
23	65473	97120	67309	80703	85621	81908	67419	62549	90349	60126	101776	121599	104334	83560
24	785	46917	47963	47759	464604	46712	45715	34698	40385	27880	47629	46944	45917	72608
25	66783	65155	61511	58616	51355	50198	45802	41796	42055	45835	43278	40859	36549	49984
26	6507	64937	61499	58424	56623	56446	46615	44427	64081	67422	53636	49459	47634	52132
27	166203	200033	175317	177279	168692	150986	124836	109444	121401	10910	118663	109109	9522	126338
28	36352	43042	42186	39772	37962	35758	30710	4025	22218	26136	40804	43056	4066	31237
29	3103	21204	21790	21455	20493	20596	21168	17944	14964	18889	24720	23460	22924	19439
30	69244	86301	67891	69688	60925	58879	57792	25988	27711	24007	82733	39817	61757	56364
31	15193	43913	42527	39229	35459	34709	35134	20533	12297	4747	47122	52056	26048	31459
32	56227	59776	63523	55482	36668	52608	51602	52559	37564	29865	36768	18997	16779	43724
33	6802	5259	8069	5007	4382	4506	4315	3375	2334	1945	3053	1493	5224	4290
34	17051	16062	26554	13874	4385	2026	594	356	88	6945	24266	9403	125	9364
35	40279	40289	74030	40039	40775	41097	40904	33590	26782	18936	36630	37178	37468	39077
36	29744	28516	32529	28642	24760	20346	18615	14129	9094	4043	6842	4957	2947	17320
37	20699	16945	21880	17173	15248	13936	13359	10032	5741	4261	9100	7167	6658	12477
38	11499	12482	10073	12558	11040	11319	15600	8123	5603	6068	9598	8219	7360	9965

* Note: The week of 10/28/88 was not used because of incomplete data.

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13. ABSTRACT *(Maximum 200 words)*

The North Boundary treatment system at Rocky Mountain Arsenal, Commerce City, Colorado, involves the pumping of contaminated groundwater from an unconfined aquifer from one side of a soil bentonite slurry wall to three pulsed-bed activated carbon absorbers and prefilter and postfilter systems. The treated water is injected into the unconfined aquifer on the other side of the slurry wall via 38 recharge wells and 15 recharge trenches, collectively referred to as the recharge system. Over time, the dewatering and especially the recharge system have a tendency to become clogged, which limits their effectiveness. A number of factors have been attributed to the degradation in performance of dewatering and recharge systems. These are air binding, sodium adsorption, metal precipitation, deposition of cementing agents, straining of suspended solids, and microbial growths or biofouling. This report presents the

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Activated carbon	Microbial fouling	Recharge capacity
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results of three separate assessments of reduced recharge capacity of a pump-and-treat system. The fate of carbon fines throughout the North Boundary system, clogging because of periodic losses of activated carbon fines, and growth of microorganisms in the recharge system are addressed.